

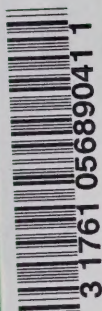
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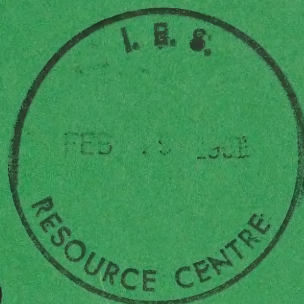
EFFECT OF PRETREATMENT ON GROUNDWATER CONTAMINATION FROM
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Ministry
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Minister

Graham W. S. Scott, Q.C.,
Deputy Minister

EFFECT OF PRETREATMENT ON
GROUNDWATER CONTAMINATION
FROM LEACHING BEDS

By

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Applied Sciences Section
Pollution Control Branch
Research Publication No. 83

July 1980

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ABSTRACT

Subsurface disposal of septic tank effluent, secondary treatment plant effluent and polishing lagoon effluent at three different locations, resulted in degradation of the groundwater quality. The level of groundwater contamination depended on the type of pretreatment provided. The septic tank effluent contributed to the highest level of groundwater contamination followed by the secondary and then the polishing lagoon effluent. A soil columns study indicated that pretreatment resulting in aerobic effluent has beneficial effect on the contaminant removal efficiency of soil. Contaminants formed their own typical dispersion plumes that tended to spread in a wedge shape extending along the direction of the groundwater. The concentrations of contaminants were highest at the point of discharge and decreased gradually with an increase of distance from the source. The subsurface movement and dispersion of contaminants varied with the hydrogeological factors and subsoil conditions.

PROJECT STAFF

The following staff of the Applied Sciences Section of the Ministry of the Environment were instrumental in the study and preparation of this report.

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1.0 INTRODUCTION

For many years, public agencies at all levels of government have been concerned about the contamination of surface water. Degradation of the quality of water on a stream or lake can be rather obvious with discolouration, odour, and floating debris. Problems of groundwater contamination have not received much attention because they are usually local in nature, and the effects are hidden from view. Several investigations, (2, 5, 7, 14), have shown that groundwater contamination may be more serious than similar contamination of surface waters and in many ways, the correction of groundwater quality degradation is considerably more complex, expensive and time consuming than in the case of surface waters.

One of the most significant sources of groundwater contamination is discharge from septic tanks, (2, 7, 14). With the increase in the number of houses served by septic tanks in recent years, millions of litres of sewage are discharged from residences into the subsurface each day. These effluents from septic tanks are sources of potential bacterial, viral and chemical contaminants, (2, 7, 14), despite the fact that septic tanks are designed to purify, to some extent, the raw sewage discharged into them. In order to protect the groundwater supplies, ways and means should be sought to reduce the load of contaminants reaching the groundwater.

Laboratory studies, (12, 13, 18), have indicated that pretreatment of sewage resulted in the reduction of contaminants concentration in the effluent. Also, there were indications of improvement in the pollutant removal efficiency of soil as a result of pretreatment.

Among the various contaminants reaching the groundwater as a result of septic tank discharges, nitrate pollution is probably the most important from a public health standpoint, (1, 10, 14). In order

to fully assess health and other hazards associated with groundwater contamination, the level of concentration and the extent of spread of the contaminants must be known. It is thus necessary to study the underground movement of the contaminants from subsurface wastewater disposal systems.

The purpose of this investigation was to:

- a) determine the effect of the type of pretreatment on the level of groundwater contamination;
- b) determine the effect of the type of pretreatment on the pollutant removal efficiency of the soil;
- c) study the underground movement of contaminants from subsurface wastewater disposal systems.

Since chemical pollutants travel farther and persist longer than bacterial pollutants, (6), and since chlorides, nitrates and sodium are considered to be the most useful indicators of groundwater pollution, (1, 11, 15, 16), this study is focused mainly on the subsurface movement of chlorides, nitrates and sodium; although concentration levels of other contaminants are also presented.

In order to achieve the desired objectives, a simultaneous field and laboratory study was conducted at the Unionville Sewage Treatment Plant Site and at the Applied Sciences Laboratory of the Ministry of the Environment. In the field study, three types of effluents, viz a septic tank (anaerobic) effluent, a secondary treatment plant (aerobic) effluent and a polishing lagoon effluent (following secondary treatment) were disposed into the ground utilizing subsurface disposal systems, to determine the effect of the type of pretreatment on the level of groundwater contamination and study the movement of the contaminants in the groundwater.

In the laboratory study, the same three effluents were passed through three different sets of three identical soil columns containing soils obtained from the three effluent disposal sites, to determine the effect of pretreatment on the pollutant removal efficiency of the soil.

2.0 MATERIALS AND TECHNIQUES

The collection of data in the field study could be divided into two phases. The preliminary data such as the determination of soil characteristics, the level of water table, direction of groundwater flow and the background chemical composition of the groundwater were obtained before the installation and operation of the subsurface disposal systems. The rest of the field data was collected after the subsurface disposal of the effluents to the end of the study. The column study was simultaneously conducted in the Applied Sciences Laboratory of the Ministry of Environment.

2.1 Site Selection

After the evaluation of various alternatives, the site at the Unionville Sewage Treatment Plant was selected for the purpose of this study. The site is located in the Regional Municipality of York, about a kilometre in the northeast direction, from the intersection of Kennedy Road and Highway 7. The location of the site is shown in Figure 1.

The Unionville Sewage Treatment Plant is an activated sludge, diffused aeration plant, equipped with a polishing lagoon, for tertiary treatment. The raw sewage entering the plant is essentially domestic in nature, as little industry is present within the collection area. The effluent after treatment is discharged into the Rouge River, which flows to the south of the treatment plant.

The main reason for selection of this site was the availability of the three types of effluent desired for the study viz a basically domestic raw sewage, aerobic secondary treatment plant effluent and polishing lagoon effluent. The other factors were the availability of land, suitability of soil and proximity of the site to the Ministry of the Environment Central Laboratories.

2.2 Soil Testing

A number of standard percolation tests were performed in accordance with the requirements of the Ministry of the Environment at the three locations selected for the disposal of septic, secondary and polishing lagoon effluents. The locations of the percolation tests are shown in Figure 2.

Several soil samples were obtained at different depths from each of the three effluent disposal sites for grain size analysis. Liquid limit, plastic limit and plasticity index were determined for each of the samples collected. The soil was classified according to the Unified Soil Classification System. The results of the soil analysis are shown in Table 1.

Three different sets of three almost identical soil columns were made from soil obtained from the absorption trench area of each of the three effluent disposal systems, as indicated in Figure 2. The stratification and soil profile as determined by visual inspection of the soil samples in the laboratory, is shown in Figure 3.

2.3 Level of the Groundwater Table

Fluctuations in the groundwater level were recorded by measuring the depth of water table in the well points, from the ground surface, on a regular basis. Data with regard to the rainfall and pan evaporation losses in the study area were obtained from the field measurements and Environment Canada Statistics.

A precipitation histogram and the mean changes in the depth of water table from the ground surface in the secondary effluent disposal area are shown in Figure 4.

2.4 Direction of Groundwater Flow

The level of the water table was obtained from measurements of the water level in the early well points driven in the study area. The direction of groundwater movement was determined by using the Three Point Method.⁽⁴⁾ The method is based on an assumption that the water table, within a limited area, is a sloping flat plane and that the groundwater moves mostly in the direction of the maximum slope of the plane.

Assuming that the levels of the water table in three well points A, B, C, which are not located on one straight line, are "a", "b", and "c" where $a > b > c$, (see figure below), there must be one point "d" on the line A-C in which if a well point D was installed, the level of the water table would be equal to "b". Any line perpendicular to B-D drawn from a point of a higher level than "b", shows the direction of maximum slope and the direction of the fastest groundwater flow.

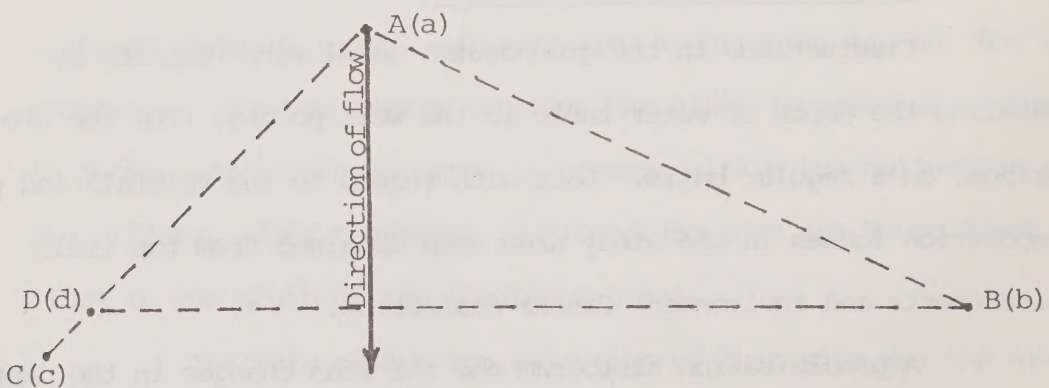


FIGURE A. "Three Point Method" Determination of Groundwater Movement.

The groundwater table contours (in metres) and the direction of the groundwater flow at the sites 'S', 'L' and 'A' are shown in Figures 7, 8 and 9, respectively.

2.5 Background Concentrations (C_b)

Groundwater samples were collected from the early well points driven in each of the effluent disposal sites to determine the concentration of contaminants in the groundwater under each disposal system, before subsurface disposal. These samples were analyzed in the Central Laboratory of the Ministry of the Environment located at Resources Road, Toronto. Results of the chemical analysis of these samples for sites 'S', 'A' and 'L' are indicated in Table 6, 7 and 8, respectively.

2.6 Effluent Disposal Systems

Three pilot wastewater disposal systems were installed at the 'S', 'L' and 'A' locations for subsurface disposal of the three types of effluents. A general layout of these systems is shown in Figure 5. The design and installation of the disposal systems were according to the requirements at that time of the Ministry of the Environment and the Regional Municipality of York Health Unit. The design and arrangement of the systems is shown in Figure 6.

A. The Septic Effluent Disposal System

This system was constructed in disturbed soil inside the Unionville Sewage Treatment Plant boundary, surrounded by a driveway on two sides, a large aerobic digester tank on one side and the plant control building on the other side, as shown in Figure 7. The system comprised one, two compartment, precast, reinforced concrete septic tank of approximately 2,300 L capacity. Raw sewage taken from the head end of the primary clarifier of the plant was used as the influent for the system.

The tank was connected to one standard 10 cm diameter PVC perforated drainage pipe 16 m in length, dosed intermittently at a rate of $25 \text{ L}/(\text{m}^2 \cdot \text{d})$. The septic (anaerobic) effluent was disposed in a 45 cm wide soil absorption trench. The soil in the area of the tile bed consisted of top soil to an average depth of 0.7 m, a shallow lens of sandy silt, and about 1 to 1.5 m of clay silt containing some sand (CL), changing to silty clay with depth and eventually pure clay in some areas.

B. The Secondary Effluent Disposal System

This system was installed in a field adjacent to the Unionville Sewage Treatment Plant which sloped down to the Rouge River, as shown in Figure 8. This system comprised a standard distribution box, two standard 10 cm diameter PVC perforated pipes, each 16 m in length, laid parallel in the absorption trenches, spaced 2 m apart and were dosed intermittently at a rate of $49 \text{ L}/(\text{m}^2 \cdot \text{d})$ with clarified secondary sewage effluent from the Unionville Sewage Treatment Plant. The soil in which the leaching bed was installed is a fill with varying percentages of clay, silt and sand to a depth of approximately 2 m, which increased in thickness to 3 m at a distance of 12 m from the bed. Below the fill was original top soil consisting of about 0.5 m of organic black material. Underlying the organic layer in the northern section of the leaching bed was a lens of sandy silt containing some clay to a depth of 0.3 m to 1 m. Below this lens and the rest of the monitoring area was a fairly homogeneous stratum of clayey silt containing some sand (CL).

C. The Lagoon Effluent Disposal System

This system was constructed in disturbed soil close to the berm of the Unionville Sewage Treatment Plant Polishing Lagoon, as shown in Figure 9. This system comprised two standard 10 cm diameter PVC perforated pipes, each 16 m in length, laid parallel 2 m apart in the absorption trenches and dosed intermittently at a rate of $49 \text{ L}/(\text{m}^2 \cdot \text{d})$ with the plant polishing lagoon effluent. The southern banks of the lagoon had been built up to a height of 1 m with silty sand and organic fill. Underlying the fill was about 0.3 m of the original top soil and a lens of sandy silt, beneath which the soil structure was similar to that in the other tile field areas.

2.7 Contamination Monitoring System

In order to study the extent of dispersion, level of concentration and subsurface movement of the contaminants, a network of sampling well points and lysimeters was installed with each subsurface effluent disposal system.

The lysimeters were standard, open top, 200 L metal drum type, installed under the perforated sewage disposal pipes in the middle of the run, on the downstream side of the groundwater flow. The sampling well points were made up of 3 cm diameter galvanized pipe sections available in 1.5 m lengths that could be joined by galvanized couplings to any desired length. The bottom 45 cm length of the well points was provided with No. 60 mesh screen for the intake of groundwater samples. The top of the well points were covered by a screw-on type, galvanized cap. The locations of the sampling well points were chosen mainly on the basis of the slope and direction of the groundwater flow and anticipated spread of contaminants. Auger holes

were bored in the chosen locations and well points were installed to the desired depths. Section of a typical well point is shown in Figure 6.

2.8 Hydraulic Loading Rate

The hydraulic loading rate and the total volume of effluent disposed by each system was recorded by a combination of a variable speed pump and timer. Each system was fed by a belt driven positive displacement pump, to give a variable flow rate, with a 24 hour timer, which had provision for 15 minute increments and 15 minute timer with 15 second increments. The systems had a solenoid valve in the feed line which controlled the feed from the plant or lagoon to the tile fields. The effluent loading rate and the total volume of the effluent disposed by each system is shown in Table 3.

2.9 Feed Concentration (C_0)

The concentration of contaminants in the feed and effluents (before subsurface disposal) was monitored by taking regular samples of the effluent at the head end of the primary tank, at the secondary clarifier prior to chlorination, at the polishing lagoon before discharge and at the influent points of the disposal systems.

These samples were analyzed in the M.O.E. Laboratory. A summary of the analysis results of these samples is presented in Table 4. A comparison of the feed quality of the three effluents before subsurface disposal is given in Table 5.

2.10 Contaminants Concentration in the Groundwater (C)

The subsurface movement of contaminants, after disposal, was monitored by taking regular samples from the lysimeters and well point network of each of the disposal systems. Variations of the concentration levels of the selected contaminants in the groundwater with time at the secondary effluent disposal site is shown in Figures 10 to 12.

The highest level of the contaminants recorded at each of the well point locations of the 'S', 'A' and 'L' sites is shown in Table 6, 7 and 8, respectively.

2.11 Contaminant Breakthrough Velocity

The breakthrough time and velocity of the contaminants were calculated from the contaminant dispersion contours plotted in accordance with the data collected from the well point network with regard to concentration variation of the contaminant, with respect to time and distance, as shown in Figures 17, 18 and 19.

Table 9 shows the breakthrough velocities of chlorides, nitrates and sodium calculated at 10 week intervals. The average breakthrough velocities of the contaminants, derived from the above data are also presented.

2.12 Adsorption Capacity of Soil

The adsorption capacity of soil could be calculated using an extension of the Langmuir's Equation, (3, 8, 19, 20). The modified form of the equation is given as follows:-

$$\frac{V_w}{V_x} = 1 + \frac{A\rho_b}{C_o f} \quad \rightarrow a$$

or

$$A = \left(\frac{V_w}{V_x} - 1 \right) \times \frac{f}{\rho_b} \times C_o \quad \rightarrow b$$

where

"A" is the adsorption capacity of the soil in micrograms per gram

"V_w" is the velocity of the water front

"V_x" is the velocity of the contaminant front

"f" is the porosity of the soil

"ρ_b" is the bulk density of the soil in grams per cubic centimetres

"C_o" is the equilibrium concentration of contaminant discharge to the ground in miligrams per litre.

In addition to the inherent assumptions in the derivation of the Langmuir's Equation, the following assumptions were made for calculation of adsorption capacity of the soil:-

1. The chloride ion is not adsorbed by the soil
(the adsorption capacity of the soil for chlorides = 0).
2. The velocity of the waterfront is equal to the velocity of the chloride front ($V_w = V_{cl}$).
3. The average breakthrough velocity of the contaminant is taken as the velocity of the contaminant front (V_x).
4. The mean concentration value of the contaminant before subsurface disposal (Table 4) is taken as the equilibrium concentration of the contaminant, discharged to the ground (C_0).

The calculated values of the bulk density (ρ_b) for the secondary treatment plant effluent disposal site was 1.92 grams per cubic centimetre and the porosity (f) of the soil was 30%. The breakthrough velocities of the selected contaminants at the secondary effluent disposal site is presented in Table 9. The adsorption capacities of the secondary effluent disposal site for the selected contaminants is given in Table 10.

2.13 Column Study

In order to study the effect of the type of wastewater treatment on the pollutant removal efficiency of soil, three different sets of three identical soil column samples were collected from the absorption trench area of the three disposal systems, as indicated in Figure 2. Samples S1, S2 and S3 were obtained from the septic effluent disposal site. Samples L4, L5 and L6 were obtained from the lagoon effluent disposal site and samples A, A8 and A9 were obtained from the secondary effluent disposal site.

Each test column contained approximately 0.9 m of top soil and 1.2 m of disturbed sub-soil separated by a 5 cm layer of pea gravel and encased in a 15 cm diameter PVC pipe about 2.13 m in height. A section of typical test column is shown in Figure 13. The characteristics of one soil sample tested from each of the three sets of soil column samples is shown in Table 11. Using pump and timer mechanisms each set of columns was fed by the same influent that was being disposed by the effluent disposal system in the field. The hydraulic loading rate and percolation rate of each column is given in Table 12. The feed entered the column through tygon tubing, into a layer of pea gravel, between the top soil and disturbed sub-soil sample, and percolated through the test soil sample. Percolation rates and chemical parameters were determined on the column effluent samples, collected from the base of the columns. The concentration of contaminants in the column effluent collected from the base of the columns is given in Table 13. Variations in the concentrations of the selected contaminants with time is shown in Figures 14, 15 and 16. The percentage removal of contaminants by test column soils is presented in Table 14.

2.14 Subsurface Movement of Contaminants

The dispersion of various levels of contaminant concentrations were based on the mean values of the dilution factor for chloride ion which was calculated for each well point in the secondary effluent disposal site, at 5 week intervals, after the period of initial breakthrough and upon reaching a relatively steady state, after saturation. The chlorides, nitrates and sodium contamination plumes were constructed at 15 week intervals and are shown for 30 week intervals in Figures 20, 21 and 22.

The variation in concentration ratio, C/Co , of chlorides, nitrates and sodium with distance, is indicated in Figures 23, 24 and 25. The distance travelled with respect to time by chlorides, nitrates and sodium ions at the concentration level $C/Co = 0.1$ is shown in Figures 26, 27, 28 and 29.

2.15 Data Analyses

Analyses of the soil data were done in the laboratory of the Applied Sciences Section of the Ministry of the Environment, using the standard procedures of soil testing and classified according to the Unified Soil Classification System. The percolation tests were performed according to the Standard Procedures of the Ministry of the Environment. Chemical analyses of the samples collected from the plant, lagoon and groundwater, were performed in the Central Laboratories of the Ministry of the Environment, according to the Standard Methods of Water Analyses, (9, 17).

All the statistical values and graphs that are presented, were analyzed on an electronic computer (HP - 9825A) and are based on standard mathematical and statistical equations and curves.

3.0 RESULTS AND DISCUSSION

3.1 Sub-Soil Conditions

Characteristics of the Unionville soil samples collected at the secondary effluent disposal site 'A', septic effluent disposal site 'S', and lagoon effluent disposal site 'L', are shown in Table 1.

Results of the grain size analyses indicate that the soil type in general was silty clay. Soil characteristics at the secondary effluent disposal site varied from silty sand (ML) to silty clay (CL). The percolation test results are given in Table 2. The percolation time at this site varied from 2.1 min/cm to 93.8 min/cm.

The soil at the septic effluent disposal site was generally a silty clay (CL) type. The percolation test results varied from 0.60 min/cm to 172.4 min/cm. The soil at the lagoon effluent disposal site varied from clayey silt (CL) to clay and silt (CI). The percolation test results varied from 2.6 min/cm to 250 min/cm.

Visual examination of the stratification and soil profile of the samples collected from the above sites also indicated the soil to be predominantly silty clay (CL), which varied in permeability according to composition and structure of the grain size. The variations in percolation time were probably due to the differences in soil composition, grain structure and sub-soil conditions.

The water table sloped toward the Rouge River and the direction of the groundwater flow was in the southwesterly direction as indicated in Figure 5.

The precipitation histogram and the mean changes in depth of water table from the ground surface, in the secondary effluent disposal area, are shown in Figure 4. The average annual mean precipitation for the period of study was 62 cms and the average annual pan evaporation loss in the subject area for the same period was 91 cms.

The mean depth of the groundwater table in the secondary effluent disposal site varied from 2.2 m to 4.9 m below the ground surface. The hydraulic loading rate (feed rate) and the effluent volume disposed by each of the disposal systems is shown in Table 3. The hydraulic loading rate for the septic tank disposal system was 171 L/d and the total volume disposed by this system was 162,108 L. The hydraulic loading rate for the secondary effluent disposal system and the lagoon effluent disposal system was 682 L/d each and the total volume disposed by these systems was 662,222 L and 606,298 L, respectively. The variation in the volume disposed by these systems is because of the number of days each system had to be shut down as a result of operational and functional problems including adverse climatical conditions.

3.2 Effect of Subsurface Disposal

The average background concentrations of the contaminants in the groundwater, at septic effluent disposal site 'S', secondary effluent disposal site 'A', and lagoon effluent disposal site 'L' are shown in Tables 6, 7 and 8, respectively. The average background concentration of nitrates in the groundwater of the study area were less than 0.2 mg/L. The highest recorded average background groundwater concentration of chlorides for sites 'S' and site 'L' were 226 mg/L and 251 mg/L, respectively, compared to site 'A' where the highest average background groundwater concentrations were 31 mg/L.

The highest recorded average background groundwater concentrations of sodium for site 'S' and site 'L' were 127 mg/L and 148 mg/L compared to site 'A' where the highest average background groundwater concentrations were 22 mg/L.

Since all the three sites 'S', 'L' and 'A' fall within the same aquifer boundary, the high groundwater concentration of contaminants at the site 'L' were later found to be due to exfiltration from the lagoon. The high groundwater concentration of contaminants at the site 'S' were later investigated and found to originate from the lagoon contents percolating through the non homogeneous fill material in which the system was situated.

An investigation was undertaken by the Ministry of the Environment in 1975 which confirmed the contamination of sites 'S' and 'L' due to exfiltration from the Unionville Sewage Treatment Plant polishing lagoon.

The concentration level range and mean value of various contaminants in the feed and effluents of the three subsurface disposal systems taken at different treatment stages of the Unionville Sewage Treatment Plant Effluent, are indicated in Table 4. The concentration of nitrates (as N) in the secondary effluent varied from <0.1 mg/L to 20 mg/L with a mean value of 4.4 mg/L. The average nitrate concentrations in the effluents from the septic tank and polishing lagoon were <0.2 mg/L and 3.5 mg/L, respectively. The higher level of nitrate concentration in the plant secondary effluent could be due to the oxidation of nitrogen and the slight reduction indicated in the polishing lagoon effluent could probably be due to conversion of nitrates into other forms. The concentration of sodium (as Na) in the secondary effluent varied from 113 mg/L to 325 mg/L, with a mean value of 215 mg/L. The average sodium concentrations in the effluents from the septic tank and polishing lagoon were 267 mg/L and 190 mg/L, respectively. The concentration of chlorides (as Cl) in the secondary effluent varied from 240 mg/L to 480 mg/L, with a mean value of 322 mg/L. The average chloride concentrations in the effluents from

septic tank and polishing lagoon were 429 mg/L and 269 mg/L, respectively. The high concentration of chlorides in the influent to the Unionville Sewage Treatment Plant was caused by the water softeners in the local subdivision which were timed to flush during the low flow period between 0100 hours and 0500 hours. A statistical comparison of the quality of the three effluents before subsurface disposal is shown in Table 5. The variations with time in the groundwater concentration of chlorides, nitrates and sodium after subsurface disposal at the secondary effluent disposal site, are shown in Figures 10, 11, 12. The highest level, after subsurface disposal, of nitrates, chlorides, and sodium recorded at each well point location of the septic effluent disposal site, secondary effluent disposal site and lagoon effluent disposal site is shown in Table 6, 7 and 8, respectively. The highest concentration levels of chlorides, sodium and nitrates recorded in the groundwater at the septic effluent disposal site were 400 mg/L, 280 mg/L and 18 mg/L, respectively; at the secondary effluent disposal site were 363 mg/L, 180 mg/L and 14 mg/L, respectively; at the lagoon effluent disposal site were 316 mg/L, 210 mg/L and 8.5 mg/L, respectively. Comparing the concentrations of nitrates, chlorides and sodium in the groundwater at the three disposal sites before and after subsurface disposal, it could be seen that the concentration of the contaminants in the groundwater increased considerably as a result of subsurface disposal of effluents.

Comparing the level of total nitrogen, sodium and chlorides in the influent to the subsurface disposal systems, it could be noticed that the influent to the septic tank had the highest level of contaminants concentration and the polishing lagoon effluent had the lowest level of concentration of the three.

Comparing the highest levels of chlorides, nitrates and sodium concentration in the groundwater after subsurface disposal, at the three disposal sites, it is evident that septic tank effluent contributed to the highest level of contaminants concentration in the groundwater. Except for the concentration of sodium, secondary treatment plant effluent contributed to the second highest level of contamination and the polishing lagoon effluent contributed to the lowest level of contamination. The higher level of sodium concentration in the polishing lagoon effluent than the secondary treatment plant effluent could be due to the desorption of sodium in the lagoon. From the above it could be concluded that pretreatment reduced the level of groundwater contamination.

3.3 Column Study

One soil column sample from each of the three sets collected from the three effluent disposal sites was analyzed. The characteristics of the test column soil are shown in Table 11. The soil in general was sandy silt (CL) with varying uniformity coefficient of 97.8 to 114.2. The permeability of soil samples varied from 5.4×10^{-5} cm/sec to 2.0×10^{-7} cms/sec.

The mean loading (feed) rate and effluent percolation rate for each of the three sets of test columns is given in Table 12. The cumulative feed time for septic effluent disposal site column samples, (S1, S2, S3), varied from 905 days to 927 days. The cumulative volume of the feed varied from 172.8 L to 239.8 L. The mean loading rate for this set varied from 0.191 L/d to 0.262 L/d. The cumulative time for effluent percolation for this test column set varied from 904 days to 939 days. The cumulative volume of effluent collected varied from 127.9 L to 197.5 L. The mean percolation rate for this set varied from 1.28×10^{-5} cm/s to 1.65×10^{-5} cm/s.

The cumulative feed time for lagoon effluent disposal site column samples, (L4, L5, L6), varied from 982 days to 985 days. The cumulative volume of the feed varied from 122.2 L to 219.7 L. The mean loading rate for the set varied from 0.170 L/d to 0.233 L/d. The cumulative time for effluent percolation for this test column set varied from 975 days to 978 days. The cumulative volume of effluent collected varied from 59.8 L to 131.7 L. The mean percolation rate for this set varied from 0.61×10^{-5} cm/s to 1.02×10^{-5} cm/s.

The cumulative feed time for secondary effluent disposal site column samples, (A7, A8, A9), was 975 days. The cumulative volume of the feed varied from 123.7 L to 197.1 L. The mean loading rate for this set varied from 0.127 L/d to 0.202 L/d. The cumulative time for effluent percolation for this test column set varied from 966 days to 977 days. The cumulative volume of effluent collected varied from 53.8 L to 121.4 L. The mean percolation rate for this set varied from 0.6×10^{-5} cm/s to 1.0×10^{-5} cm/s. The average concentration of total nitrogen, sodium and chlorides in the septic influent was 28.97 mg/L, 267 mg/L and 428.8 mg/L, respectively. The average concentration of total nitrogen, sodium and chlorides in the column effluents fed with septic influent was 11.06 mg/L, 243.9 mg/L and 428 mg/L, respectively.

The variations in the effluent volume collected could be due to the variations in the permeability of the soil medium (as shown in Table 11), evaporation losses and/or clogging of the soil by sewage.

The column study indicated that the effluent from the columns fed with septic effluent had the highest average concentration of total nitrogen, chlorides and sodium as shown in Table 13. This probably is due to the fact that the septic tank effluent feed initially had the highest average concentration of total nitrogen, chlorides and sodium as shown in Table 14. This shows that higher concentration of

contaminants in feed ultimately result in higher concentration of contaminants in the effluent. The effluent of columns fed with lagoon effluent was higher in total nitrogen and sodium concentrations than those fed with secondary effluent. This could probably be due to the oxidation and hence conversion of secondary treatment plant effluent nitrogen into nitrates and desorption of sodium in the lagoon effluent fed soil columns. The average concentration of chlorides was higher in the effluent of columns fed with secondary effluent than those fed by lagoon effluent; this could be due to the initial higher chlorides concentration level in the secondary treatment plant effluent compared to the lagoon effluent.

The percentage removal of pollutants from the feed by the test column soils is indicated in Table 14. The highest percentage removal of total nitrogen (96%) and sodium (22%) is indicated by the secondary effluent disposal site soil columns. The highest increase, (23%), indicated in case of chlorides could probably be due to the initial higher concentration of chlorides in the secondary treatment plant effluent resulting in desorption after the saturation stage. The soil conditions being more or less the same, the pollutant removal efficiency could be attributed to the aerobic effluent, which seems to have a beneficial influence upon the soil for pollutants removal.

The percentage removal of total nitrogen and increase in the level of chlorides concentrations were 93% and 21%, respectively, in case of lagoon effluent disposal site soil columns as compared to the percentage removal of 62% and 0.2%, respectively, for septic effluent disposal site soil columns. The percentage removal of sodium was 9% in case of septic effluent disposal site soil columns, and an increase of 2% was indicated in case of lagoon effluent disposal site soil columns, most probably as a result of sodium desorption. The increase

indicated in chlorides concentration in case of lagoon effluent disposal site soil columns was probably due to the desorption of chlorides by the soil after the breakthrough stage. From the above results, it could be seen in general, that pretreatment of feed and presence of dissolved oxygen in the effluent seem to have beneficial effect on the efficiency of soil for contaminants removal.

Figures 14, 15 and 16 indicated the variation of nitrogen, sodium, chlorides and feed concentrations in the test columns soils with respect to time. The chloride and sodium concentrations for all the columns stayed under the feed concentrations in the initial stages due to the attenuation reactions of the soil. After the breakthrough, the concentrations stayed above the feed level due to increase in concentration levels as a result of evaporation of feed and desorption of contaminants. The nitrate concentration levels stayed well under the feed concentration levels (which were given for total nitrogen) for all the columns. The low levels of nitrates in the column effluents could be due to denitrification reactions in the test soil as a result of prevailing anaerobic conditions.

Since it was not intended to duplicate the field conditions in the laboratory, the effect of temperature on laboratory soil columns was not controlled to correspond with that found in natural conditions.

The effect of pH on the laboratory soil columns was monitored, which varied from neutral to alkaline, for the period of this study.

3.4 Subsurface Movement of Contaminants

Because of the interferences and precontamination of the lagoon effluent disposal site and the septic effluent disposal site, due to exfiltration from the lagoon, the study of the subsurface movement of the contaminants was restricted to the secondary effluent disposal site. Table 9 gives the distance travelled and breakthrough field velocities of chlorides, nitrates and sodium that varied with

time, for every 10 week interval. The mean breakthrough velocities of chlorides, nitrates and sodium were calculated to be 0.051 m/d, 0.037 m/d and 0.027 m/d, respectively. The adsorption capacity of the secondary effluent disposal site soil for chlorides, nitrates and sodium were calculated using the modified version of the Langmuir's Equation as explained in section 2.12. The adsorption capacity of nitrates were calculated to be 0.245 $\mu\text{g/g}$, which is not significant, and hence it could be said that having reached the water table, the nitrates move quite freely in the groundwater. The main source of sodium in the effluent was common salt. Due to the chemical attraction of the sodium to certain types of soils there was a higher ratio of chlorides to the sodium in the groundwater. The adsorption capacity for sodium was calculated to be 30.376 $\mu\text{g/g}$ of soil, indicating the higher adsorption of sodium as a result of chemical reactions in the soil.

The chlorides, nitrates and sodium ions after reaching the groundwater tend to form their own contamination plumes, which seem to move downgradient generally in the direction of the groundwater flow, according to the laws of fluid movement in saturated soil. The contamination plumes for chloride, nitrates and sodium are constructed for different concentration levels at 15 week intervals and are shown for 30 week intervals in the figures 20, 21 and 22. The various patterns of dispersion could be due to the variations in the different sub-soil and hydrogeological factors, such as the effect of soil structure and composition, presence of clay lenses, resultant groundwater velocity, fluctuations of water table, densities of the contaminants and attenuation reactions in the soil, etc.

In general, the contaminant dispersion was in a wedge-type shape, which extended along the direction of groundwater flow.

The variations in concentration levels of the chlorides, nitrates and sodium contaminant fronts with distance, at 15 week intervals, are indicated by Figures 23, 24 and 25. The ratio of the concentration of contaminant in the groundwater (C) to the concentration of contaminant in the effluent before subsurface disposal (C_0) decreases with the increase in the distance of contaminant fronts from the source, the maximum level of concentration being at the point of effluent disposal. The distance recorded after 143 weeks for the concentration ratio C/C_0 to fall to 0.1 level was 25.63 m for chlorides, 18.72 m for nitrates and 18.78 m for sodium.

The time taken and the distances travelled by the chlorides, nitrates and sodium contaminant fronts at concentration level of $C/C_0 = 0.1$ is indicated in Figures 26, 27, 28 and 29. The velocity of the chloride front varied from 0.026 m/d to 0.093 m/d, with a median value of 0.037 m/d. The velocity of the nitrate front varied from 0.013 m/d to 0.050 m/d, with a median value of 0.019 m/d. The velocity of the sodium front varied from 0.019 m/d to 0.031 m/d, with a median value of 0.024 m/d. From these results, it could be seen that the underground movement of the contaminant fronts was very slow and varied for different types of contaminants under different soil and hydro-geological conditions. The higher velocity of sodium front for concentration level $C/C_0 = 0.1$ compared to the nitrates front, could be due to the chemical reactions of the soil and other subsurface phenomena, rather than actual movement of the contaminant.

4.0 SUMMARY

A field investigation was conducted at the Unionville Sewage Treatment Plant Site to determine the effect of the type of pretreatment on the level of groundwater contamination and study the underground movement of selected contaminants. A simultaneous soil column study was conducted at the Applied Sciences Laboratory of the Ministry of the Environment to determine the effect of pretreatment on the pollutant removal efficiency of the soil.

- The average background concentration of nitrates in the groundwater of the study area was 0.2 mg/L. The average background concentrations of chlorides in the groundwater for site 'S', site 'L' and site 'A' were 226 mg/L, 251 mg/L and 31 mg/L, respectively. The average background groundwater concentrations of sodium for site 'S', site 'L' and site 'A' were 127 mg/L, 148 mg/L and 22 mg/L, respectively.
- The average concentrations of nitrates (as N) in the feed to the secondary effluent disposal system, septic effluent disposal system and lagoon effluent disposal system were 4.4 mg/L (mean value), <0.2 mg/L and 3.5 mg/L, respectively. The average concentrations of chlorides (as Cl) in the effluents of the secondary effluent disposal system, septic effluent disposal system and lagoon effluent disposal system were 322 mg/L (mean value), 429 mg/L and 269 mg/L, respectively. The average concentrations of sodium in the effluents of the secondary effluent disposal system, septic effluent disposal system and lagoon effluent disposal system were 215 mg/L (mean value), 267 mg/L and 190 mg/L, respectively.

- The highest concentration levels after subsurface disposal of chlorides, sodium and nitrates recorded in the groundwater at the septic effluent disposal site were 400 mg/L, 280 mg/L and 18 mg/L, respectively; at the secondary effluent disposal site were 363 mg/L, 180 mg/L and 14 mg/L, respectively; and at the lagoon effluent disposal site were 316 mg/L, 210 mg/L and 8.5 mg/L, respectively.
- In the column study, the average concentrations of total nitrogen, sodium and chlorides in the septic tank effluent feed were 28.97 mg/L, 267 mg/L and 428.8 mg/L, respectively. The average concentrations of total nitrogen, sodium and chlorides in the column effluents fed with septic tank effluent were 11.06 mg/L, 243.9 mg/L and 428 mg/L, respectively. The percentage removal of total nitrogen, sodium and chlorides for this set was approximately 62%, 9% and 0.2%, respectively. The average concentrations of total nitrogen, sodium and chlorides in the secondary plant effluent feed were 24.4 mg/L, 214.9 mg/L and 321.6 mg/L, respectively. The average concentrations of total nitrogen, sodium and chlorides in the effluent of the columns fed with secondary effluent were 1.07 mg/L, 167 mg/L and 395.9 mg/L, respectively. The percentage removal of total nitrogen and sodium for this set was approximately 96% and 22%, respectively. There was an increase of 23%, in chlorides concentration. The average concentrations of total nitrogen, sodium and chlorides in the lagoon effluent feed were 18.3 mg/L, 189.7 mg/L and 269 mg/L,

respectively. The average concentrations of total nitrogen, sodium and chlorides in the effluent of the columns fed with lagoon effluent were 1.3 mg/L, 193.1 mg/L and 324.6 mg/L, respectively. The percentage removal of total nitrogen for this set was 93%. There was a 2% and 21% increase indicated in the sodium and chlorides concentrations, respectively.

- The mean breakthrough velocities of chlorides, nitrates and sodium were calculated to be 0.051 m/d, 0.037 m/d and 0.027 m/d, respectively.
- From the field study the calculated adsorption capacity for sodium and nitrates was 30.4 $\mu\text{g/g}$ and 0.25 $\mu\text{g/g}$, respectively. The contamination plume for chlorides, nitrates and sodium indicated a wedge type of spread which extended along the direction of the groundwater flow. The maximum concentrations of chlorides, nitrates and sodium occurred at the point of effluent discharge and then the concentrations decreased gradually with the increase in distance from the point of discharge. The distance recorded in 143 weeks time for the concentration ratio C/C_0 to fall to 0.1 level was 25.63 m for chlorides, 18.72 m for nitrates and 18.78 m for sodium. The median value of the velocity of the contaminant front at the concentration level of $C/C_0 = 0.1$ for chlorides, nitrates and sodium was calculated to be 0.037 m/d, 0.019 m/d and 0.024 m/d, respectively.

5.0 CONCLUSION AND RECOMMENDATION

On the basis of information collected and presented as part of this study, it is concluded that the subsurface disposal of treated sewage will result in the degradation of groundwater quality, the degree of contamination being a function of the quality of the material discharged.

It is recommended that careful design consideration be given to the implications of groundwater contamination, particularly in the cases of large systems or of many small systems close together.

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WELL NO.	DEPTH (m)	DATE	TIME (h)	TEMP (°C)	WATER CONTENT (%)	SHRINKAGE (%)	PLASTIC LIMIT (%)	SHRINKAGE LIMIT (%)	WATER RATIO (%)
1-1 (Average Effluent Sampled 11/10)	0.00 - 1.00	1	10	10	10.0	15.0	10.0	10.0	10.0
	1.00 - 2.00	2	10	10	10.0	10.0	10.0	10.0	10.0
	2.00 - 3.00	3	10	10	10.0	10.0	10.0	10.0	10.0
	3.00 - 4.00	4	10	10	10.0	10.0	10.0	10.0	10.0
	4.00 - 5.00	5	10	10	10.0	10.0	10.0	10.0	10.0
1-2 (Average Effluent Sampled 11/10)	0.00 - 1.00	6	10	10	10.0	10.0	10.0	10.0	10.0
	1.00 - 2.00	7	10	10	10.0	10.0	10.0	10.0	10.0
	2.00 - 3.00	8	10	10	10.0	10.0	10.0	10.0	10.0
	3.00 - 4.00	9	10	10	10.0	10.0	10.0	10.0	10.0
	4.00 - 5.00	10	10	10	10.0	10.0	10.0	10.0	10.0
1-3 (Average Effluent Sampled 11/10)	0.00 - 1.00	11	10	10	10.0	10.0	10.0	10.0	10.0
	1.00 - 2.00	12	10	10	10.0	10.0	10.0	10.0	10.0
	2.00 - 3.00	13	10	10	10.0	10.0	10.0	10.0	10.0
	3.00 - 4.00	14	10	10	10.0	10.0	10.0	10.0	10.0
	4.00 - 5.00	15	10	10	10.0	10.0	10.0	10.0	10.0

TABLES

TABLE 1

CHARACTERISTICS OF UNIONVILLE SOIL

BORE HOLE NO.	DEPTH (m)	GRAVEL (%)	SAND (%)	SILT (%)	CLAY (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	SOIL * TYPE
A-9 (Secondary Effluent Disposal Site)	0.89 - 1.04	6	29	30	35	29.6	15.3	14.3	CL
	1.60 - 1.70	4	33	28	35	31.5	16.5	15.0	CL
	2.31 - 2.57	2	28	30	32	28.8	14.7	14.1	CL
	3.50 - 3.73	9	27	31	33	32.6	14.9	17.7	CL
	4.22 - 5.0	9	52	26	13	13.9	11.5	2.4	ML
S-5 (Septic Effluent Disposal Site)	0.76 - 0.91	0	14	57	29	27	15.4	11.6	CL
	1.52 - 1.63	5	17	30	48	33.8	15.7	18.1	CL
	1.73 - 2.03	1	5	26	68	40.9	18.1	22.8	CL
L-9 (Lagoon Effluent Disposal Site)	1.57 - 1.68	1	29	35	35	40.6	17.1	23.5	CI
	2.92 - 3.18	1	22	40	37	28.5	14.1	14.5	CL

* According to Unified Soil Classification System

TABLE 2

SUMMARY OF PERCOLATION TEST RESULTS *

DATE (1972)	SEPTIC EFFLUENT DISPOSAL SITE				SECONDARY EFFLUENT DISPOSAL SITE				LAGOON EFFLUENT DISPOSAL SITE		
	Test Location				Test Location				Test Location		
	S1	S2	S3	S4	A	B	C	D	L1	L2	L3
July 26	0.59	172.4	-	-	-	-	-	-	250	-	-
July 29	0.60	171.8	-	4.2	2.7	2.1	2.9	10.5	157	5.4	-
August 3	0.56	68.8	-	4.1	4.7	3.8	6.8	93.8	42	7.7	2.6

* All results are reported in min/cm.

TABLE 3

LOADING RATE AND EFFLUENT VOLUME DISPOSED BY THE SYSTEM

TYPE OF EFFLUENT DISPOSED BY THE SYSTEM	TOTAL TIME OF OPERATION (Days)	TIME SYSTEM DID NOT OPERATE (Days)	TIME SYSTEM OPERATED (Days)	LOADING RATE (L/d)	TOTAL VOLUME DISPOSED (L)
Septic Tank	1008	60	948	171	162,108
Plant's Secondary	1008	37	971	682	662,222
Polishing Lagoon	1008	119	889	682	606,298

TABLE 4

CONCENTRATION OF CONTAMINANTS IN THE FEED AND EFFLUENTS BEFORE SUBSURFACE DISPOSAL

CONTAMINANTS AND * OTHER PARAMETERS	RAW SEWAGE		SEPTIC TANK FEED		SEPTIC TANK EFFLUENT		PLANT'S SECONDARY EFFLUENT		POLISHING LAGOON EFFLUENT	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
pH	6.9 - 8.7	7.6	6.9 - 8.2	7.6	6.4 - 8.3	7.5	6.4 - 8.4	7.5	6.7 - 9.1	7.8
BOD ₅	85 - 320	149	30 - 280	109	6 - 130	38	3 - 65	23	3 - 65	20
Suspended Solids	50 - 325	156	40 - 250	121	<15 - 200	30	5 - 70	19	<15 - 60	19
Ammonia (as N)	12 - 66	26	11 - 60	19	14 - 38	23	<0.1 - 30	14	<0.1 - 24	11
Total Kjeldahl (as N)	14 - 90	39	16 - 72	30	14 - 55	29	1 - 38	18	1 - 25	14
Nitrite (as N)	<0.02 - 0.76	<0.1	0.01 - 9.4	<0.1	0.01 - 0.8	<0.1	0.01 - 15	1.6	<0.01 - 88	1.3
Nitrate (as N)	<0.1 - 0.6	0.1	<0.1 - 2.4	0.1	<0.1 - 2.5	<0.2	0.1 - 20	4.4	0.1 - 19	3.5
Total Phosphorus (as P)	5.3 - 22	9.8	2.6 - 18	7.3	2 - 12	6.9	3 - 8.1	5.5	2 - 10	5.6
Soluble Phosphorus (as p)	1.5 - 20	6.5	0.6 - 10	4.3	2.8 - 11	5.7	1.9 - 7.0	4.5	0.8 - 8.5	4.7
Sodium (as Na)	69 - 220	164	90 - 500	296	120 - 360	267	113 - 325	215	90 - 300	190
Potassium (as K)	8.6 - 17	12.2	5.1 - 14	11.4	9 - 20	14.8	4.0 - 19	11.4	8.6 - 18	11.5
Chlorides (as Cl)	82 - 266	155	119 - 886	532	309 - 734	429	240 - 480	322	216 - 380	269
Calcium (as Ca)	19 - 91	58	32 - 168	110.6	77 - 146	103.9	45 - 148	91.9	62 - 114	84.2
Sulphates (as SO ₄)	68 - 75	71	50 - 97	74.9	30 - 104	65.5	38 - 105	72.5	49 - 91	68.6
Conductivity (as $\mu\text{mho/cm}$)	1290 - 1500	1387	1970 - 3700	2615	1975 - 2600	2254	1800 - 2300	2031	1540 - 1700	1620
Hardness (as CaCO ₃)	196 - 336	256	234 - 592	419	350 - 516	397	230 - 484	338	162 - 398	315
Alkalinity (as CaCO ₃)	279 - 524	389	296 - 460	368	201 - 445	398	193 - 410	321	191 - 380	309

* All concentrations are reported in mg/L except pH and Conductivity.

TABLE 5

COMPARISON OF THE QUALITY OF EFFLUENTS BEFORE SUBSURFACE DISPOSAL

CONTAMINANTS AND * OTHER PARAMETERS	SEPTIC TANK EFFLUENT				PLANT'S SECONDARY EFFLUENT				POLISHING LAGOON EFFLUENT			
	Values % of time equal to or less than				Values % of time equal to or less than				Values % of time equal to or less than			
	No. of Tests	15%	50%	85%	No. of Tests	15%	50%	85%	No. of Tests	15%	50%	85%
BOD ₅	115	21	37	57	117	10	23	34	110	6.6	14	29
Total Solids	81	1145	1225	1365	81	885	1000	1155	78	835	905	975
Suspended Solids	106	15	25	35	109	15	20	35	105	15	20	30
Ammonia (as N)	118	18	24	29	115	5.7	16	23	115	3.6	12	19
Total Kjeldahl (as N)	118	24	30	35	101	9.6	21	31	87	5.5	15	23
Total Phosphorus (as P)	117	5.3	7.1	8.1	120	3.7	5.4	6.7	107	3.6	5.6	6.7
Soluble Phosphorus (as P)	109	4.1	5.4	7.1	109	2.1	4.5	5.5	107	2.8	4.7	5.8
Sodium (as Na)	113	210	270	330	92	170	209	253	81	159	189	216
Potassium (as K)					107	9.5	11	13				
Chloride (as Cl)	117	354	430	496	95	256	311	373	94	230	267	300
Calcium (as Ca)	103	88	105	121	92	72	86	109	81	69	84	100

* All values are reported in mg/L

TABLE 6

CONCENTRATIONS OF CONTAMINANTS IN THE GROUND WATER BEFORE AND AFTER
SUBSURFACE DISPOSAL AT THE SEPTIC EFFLUENT DISPOSAL SITE

WELL POINT LOCATION	CONCENTRATIONS BEFORE SUBSURFACE DISPOSAL (Avg. Background Values in mg/L)										CONCENTRATIONS AFTER SUBSURFACE DISPOSAL (Highest values in mg/L)		
	Chloride	Sodium	Nitrate	Potassium	Calcium	Sulphate	Hardness	Alkalinity			Chloride	Sodium	Nitrate
S-1	47.1	17.8	<0.2	1.7	108.5	57	371	299			316	150	17
S-2	10.7	13.8	<0.2	1.7	35.2	43	226	184			70	20	0.8
S-3	83.2	16.6	<0.2	2.2	125.0	113	481	263			400	280	16
S-4	54.8	21.1	<0.2	3.1	92.0	106	461	345			400	210	18
S-5	84.9	38.0	<0.2	3.0	48.0	90	153	34			176	100	1.8
S-6	225.9	126.7	<0.2	6.0	111.0	86	401	341			298	198	4.4
S-7	13.7	21.3	<0.2	2.5	21.0	88	110	90			132	44	6.2
S-8	52.2	13.0	<0.2	1.5	43.0	60	192	85			100	30	8.7
S-9	29.2	10.9	<0.2	1.8	24.0	58	93	53			280	42	7.9
*S-13	23.1	15.9	<0.2	2.1	54.3	41.2	265.5	245			93	24	0
*S-14	35.6	28.8	<0.2	3.3	33.9	33.8	251.0	223.1			123	40	0
Field Average	41.9	19.9	<0.2	2.6	63.3	70.5	272	196.6			400**	280**	18**

* These well points were drilled one year after the feed was started.

** Highest value in the Study Area.

TABLE 7

CONCENTRATIONS OF CONTAMINANTS IN THE GROUND WATER BEFORE AND AFTER
SUBSURFACE DISPOSAL AT THE SECONDARY EFFLUENT DISPOSAL SITE

WELL POINT LOCATION	CONCENTRATIONS BEFORE SUBSURFACE DISPOSAL (Avg. Background Values in mg/L)								CONCENTRATIONS AFTER SUBSURFACE DISPOSAL (Highest values in mg/L)		
	Chloride	Sodium	Nitrate	Potassium	Calcium	Sulphate	Hardness	Alkalinity	Chloride	Sodium	Nitrate
A-2	29.4	13.3	<0.2	1.13	168	120	580	419	271	110	9.6
A-3	27.0	13.8	<0.2	1.00	121	90	412	289	310	160	14.0
A-4	30.6	10.6	<0.2	1.00	123	50	411	351	363	170	11.0
A-5	22.4	14.4	<0.2	1.14	136	110	400	282	315	160	7.7
A-6	23.7	12.4	<0.2	1.20	127	80	382	281	241	78	7.3
A-7	25.1	21.6	<0.2	1.09	134	160	458	372	255	86	4.6
A-8	25.1	18.7	<0.2	1.04	115	120	405	283	298	93	9.8
A-9	23.6	12.8	<0.2	1.16	144	-	467	424	311	120	13.0
Field Average	25.9	14.7	<0.2	1.1	133.5	104	439	338	363**	170**	14.0**
*A-12	64.7	26.3	<0.2	1.25	180	78.5	561	354	261	95	6.5
*A-13	38.1	21.8	<0.2	2.5	82.2	115	319	217	179	37	4.4
*A-14	99.3	25.1	<0.2	2.3	63.6	100	314	137	291	49	7.9
*A-15	209.0	38.9	<0.2	1.3	215	72.2	643	386	339	180	10.0
*A-16	161.1	20.7	<0.2	2.1	246	185	821	512	210	80	0.4
*A-17	46.6	16.8	<0.2	4.2	224	166	778	633	111	25	0.5
*A-18	41.2	17.6	<0.2	2.8	254	240	859	647	98	26	0.1
Field Average	94.3	23.9	<0.2	24	180.7	136.7	614	412	339**	180**	10.0**

* These well points were drilled one year after the Feed was started.

** Highest value in the Study Area

TABLE 8

CONCENTRATIONS OF CONTAMINANTS IN THE GROUND WATER BEFORE AND AFTER
SUBSURFACE DISPOSAL AT THE LAGOON EFFLUENT DISPOSAL SITE

WELL POINT LOCATION	CONCENTRATIONS BEFORE SUBSURFACE DISPOSAL (Avg. Background Values in mg/L)								CONCENTRATIONS AFTER SUBSURFACE DISPOSAL (Highest values in mg/L)		
	Chloride	Sodium	Nitrate	Potassium	Calcium	Sulphate	Hardness	Alkalinity	Chloride	Sodium	Nitrate
L-1	197.7	106.2	<0.2	0.9	131.4	62.3	384	345	306	186	8.0
L-2	192.5	62.7	<0.2	1.01	179.6	62.0	553	391	280	165	2.5
L-3	201.4	121.1	<0.2	1.0	103.8	90.0	320	236	316	190	8.5
L-4	220.6	147.9	<0.2	3.8	97.2	72.0	337	319	310	210	1.8
L-5	200.0	114.1	<0.2	1.2	113.6	70.0	344	282	314	172	2.0
L-6	207.6	119.7	<0.2	1.13	122.2	68.5	351	287	308	198	1.2
L-7	200.2	131.5	<0.2	1.1	38.8	41.5	128	161	302	190	0
L-8	214.1	140.6	<0.2	1.1	64.4	67.5	244	234	296	200	1.6
L-9	199.6	125.6	<0.2	1.4	115.0	45.0	340	294	304	184	5.5
*L-12	251.2	124.8	<0.2	0.8	139.6	33.5	421.4	303.2	316	178	0.6
*L-13	236.1	125.2	<0.2	1.4	118.8	30.2	369.6	251.9	290	170	5.0
Field Average	211.0	119.9	<0.2	1.35	111.3	41.2	344.7	282.2	316**	210**	8.5**

* These well points were drilled one year after the feed was started.

** Highest value in the Study Area

TABLE 9

DISTANCE TRAVELLED AND BREAKTHROUGH FIELD VELOCITIES
OF THE SELECTED CONTAMINANTS AT THE SECONDARY EFFLUENT DISPOSAL SITE

BREAKTHROUGH TIME IN WEEKS	CHLORIDE		NITRATE		SODIUM	
	Distance Travelled (m)	Field Velocity (m/d)	Distance Travelled (m)	Field Velocity (m/d)	Distance Travelled (m)	Field Velocity (m/d)
10	4.3	0.061	3.19	0.046	2.07	0.030
20	6.96	0.050	6.67	0.048	3.01	0.022
30	8.84	0.042	7.99	0.038	6.39	0.030
40	10.72	0.038	9.31	0.033	7.33	0.030
50	21.06	0.060	10.62	0.030	8.46	0.024
60	21.62	0.052	11.94	0.028	10.90	0.026
70	-	-	-	-	13.35	0.027
80	-	-	-	-	15.04	0.027
Breakthrough Velocity (Avg.)	0.051 m/d		0.037 m/d		0.027 m/d	

TABLE 10

ADSORPTION CAPACITY OF UNIONVILLE SOIL FOR THE SELECTED
CONTAMINANTS AT THE SECONDARY EFFLUENT DISPOSAL SITE

CONTAMINANT	C _x Average Feed Concentration (mg/L)	V _w Velocity of Water Front (m/d)	V _x * Velocity of Contaminant Front (m/d)	A Adsorption Capacity (µg/g)
CHLORIDE	322	0.051	0.051	0
NITRATE	4.4	0.051	0.037	0.245
SODIUM	215	0.051	0.027	30.376

V_w = V_{cl} (assumption)

* V_x = Breakthrough velocity of the Contaminant

TABLE 11

CHARACTERISTICS OF TEST COLUMN SOILS

COLUMN NO.	DEPTH (m)	GRAVEL (%)	SAND (%)	SILT (%)	CLAY (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	COEFF. OF UNIFORMITY	PERMEABILITY cm/sec	SOIL* Type
S-1	1.52	1	30	51	18	24.4	14.4	10.0	114.2	5.4×10^{-5}	CL
S-2	-	-	-	-	-	-	-	-	110.2	3.59×10^{-6}	-
L-4	1.52	6	47	32	15	23.7	15.7	8.0	112.2	2.02×10^{-7}	CL
L-6	-	-	-	-	-	-	-	-	107.4	3.4×10^{-5}	-
A-8	1.83	2	33	40	25	30.4	16.1	14.3	105.8	4.2×10^{-5}	CL
A-9	-	-	-	-	-	-	-	-	97.8	6.47×10^{-7}	-

* According to UNIFIED SOIL CLASSIFICATION SYSTEM

- Not Tested

TABLE 12

LOADING AND PERCOLATION RATES OF TEST COLUMNS

COLUMN NO.	F E E D				E F F U E N T			
	CUMULATIVE TIME (DAYS)	CUMULATIVE VOLUME (L)	LOADING RATE (L/d)		CUMULATIVE TIME (DAYS)	CUMULATIVE VOLUME (L)	PERCOLATION RATE	
			RANGE	MEAN			RANGE	MEAN
S-1	905	172.8	0.425 - 0.084	0.191	904	127.9	3.4×10^{-5} - 0.28×10^{-5}	1.28×10^{-5}
S-2	927	236.7	0.406 - 0.136	0.255	939	196.2	3.9×10^{-5} - 0.56×10^{-5}	1.65×10^{-5}
S-3	915	239.8	0.468 - 0.132	0.262	930	197.5	3.3×10^{-5} - 0.73×10^{-5}	1.62×10^{-5}
L-4	985	219.7	0.727 - 0.157	0.223	978	131.7	1.7×10^{-5} - 0.40×10^{-5}	1.02×10^{-5}
L-5	982	122.2	0.797 - 0.070	0.124	975	59.8	2.4×10^{-5} - 0.16×10^{-5}	0.61×10^{-5}
L-6	982	166.5	0.756 - 0.098	0.170	975	71.4	2.6×10^{-5} - 0.10×10^{-5}	0.78×10^{-5}
A-7	975	123.7	0.593 - 0.081	0.127	977	64.8	3.5×10^{-5} - 0.21×10^{-5}	0.68×10^{-5}
A-8	975	124.5	0.565 - 0.081	0.128	967	53.8	2.7×10^{-5} - 0.13×10^{-5}	0.60×10^{-5}
A-9	975	197.1	0.672 - 0.134	0.202	966	121.4	2.8×10^{-5} - 0.4×10^{-5}	1.00×10^{-5}

TABLE 13

CONCENTRATION OF CONTAMINANTS AFTER PERCOLATION

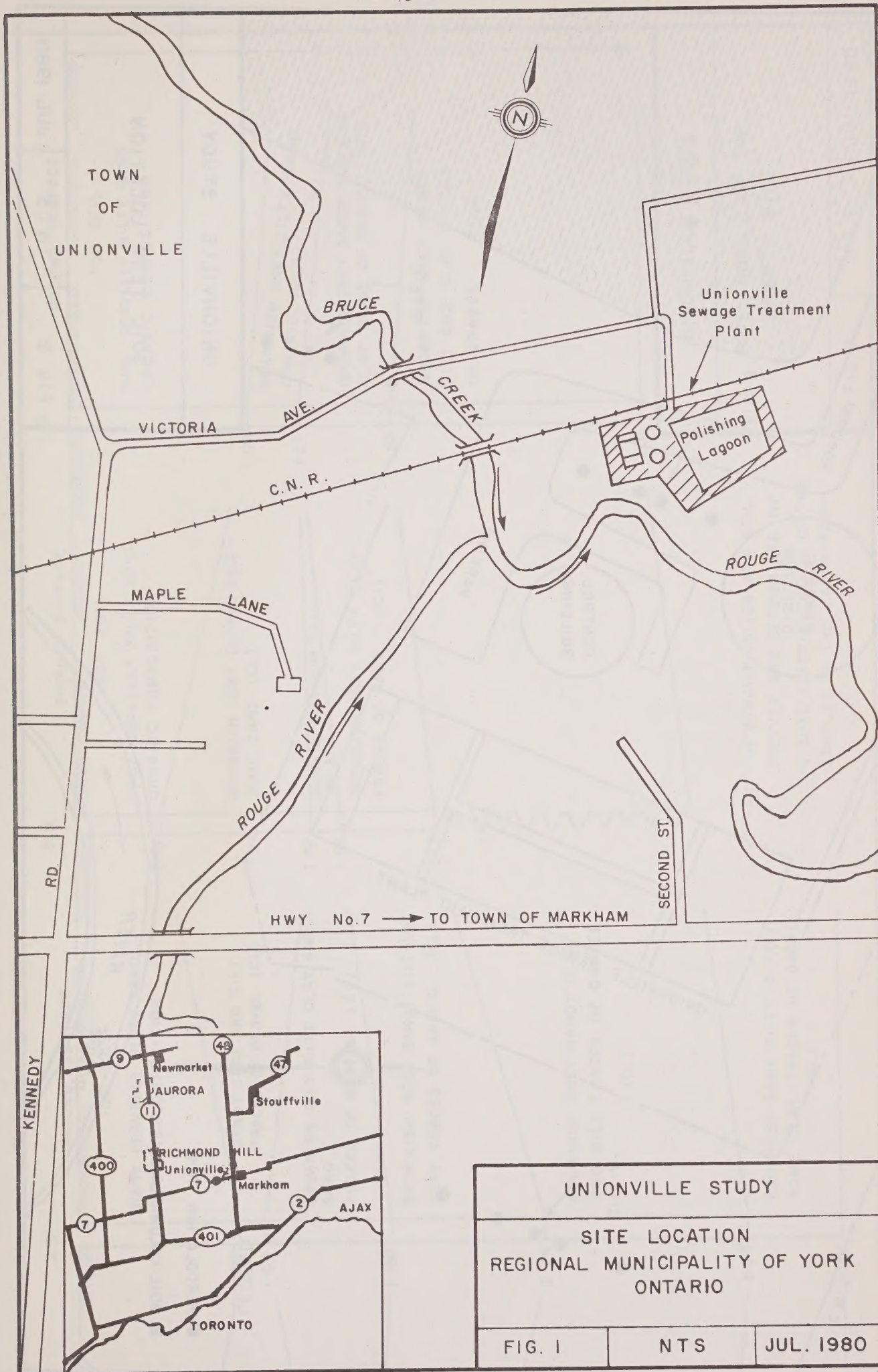
CONTAMINANTS * AND OTHER PARAMETERS	SEPTIC TANK EFFLUENT FEED				POLISHING LAGOON EFFLUENT FEED				PLANT'S SECONDARY EFFLUENT FEED			
	Col. 1	Col. 2	Col. 3	Avg.	Col. 4	Col. 5	Col. 6	Avg.	Col. 7	Col. 8	Col. 9	Avg.
pH	8.12	8.0	7.94	8.02	8.07	8.13	8.11	8.10	8.06	8.01	8.17	8.08
BOD ₅	1.5	0.65	0.92	1.02	0.57	0.69	0.82	0.69	0.85	0.93	0.7	0.83
Total Solids	1189	1191	1174	1185	910.5	897	885	898.5	863.9	880.9	1053	932.6
Suspended Solids	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Total Nitrogen (as N)	10.91	10.8	11.39	11.06	0.86	2.21	0.84	1.30	0.61	0.65	1.95	1.07
Total Phosphorus (as P)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Sodium (as Na)	241	243.4	247.2	243.9	208.2	178	193	193.1	190.1	173.2	137.7	167
Potassium (as K)	1.75	1.62	1.65	1.67	3.38	3.73	3.59	3.57	2.07	2.36	2.09	2.17
Chlorides (as Cl)	437.9	422.6	423.4	428	338.5	311	324.4	324.6	394	394.5	399.3	395.9
Calcium (as Ca)	127.3	125.1	125.4	125.9	110.7	129.6	102.7	114.3	121.4	127.5	127.9	125.6
Sulphates (as SO ₄)	66.0	67.8	68.8	67.5	48.5	30.1	58	45.5	29.9	35.3	53.2	39.5
Hardness (as CaCO ₃)	419.3	386.1	393.9	399.8	356.2	411.5	344	370.6	400.5	409.2	391.8	400.5
Alkalinity (as CaCO ₃)	236.4	204.4	228.5	223.1	261.6	319.1	239.8	273.5	224.9	182.4	278.5	228.6
Conductivity (as μ mho/cm) 2039		2078	2083	2067	1745	1729	1690.5	1721	1945	1961	1875	1927

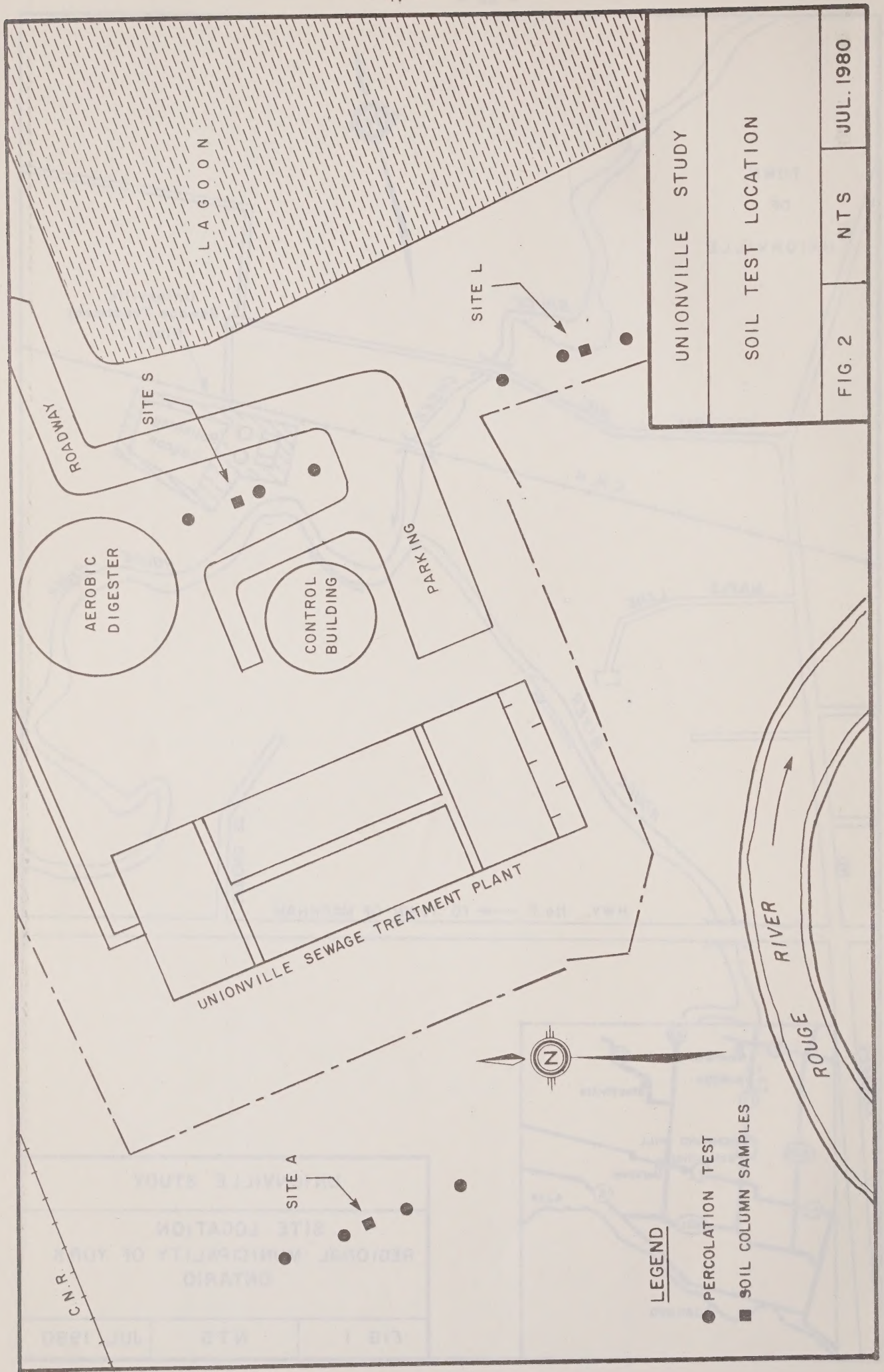
*All concentrations are reported in mg/l except pH and Conductivity

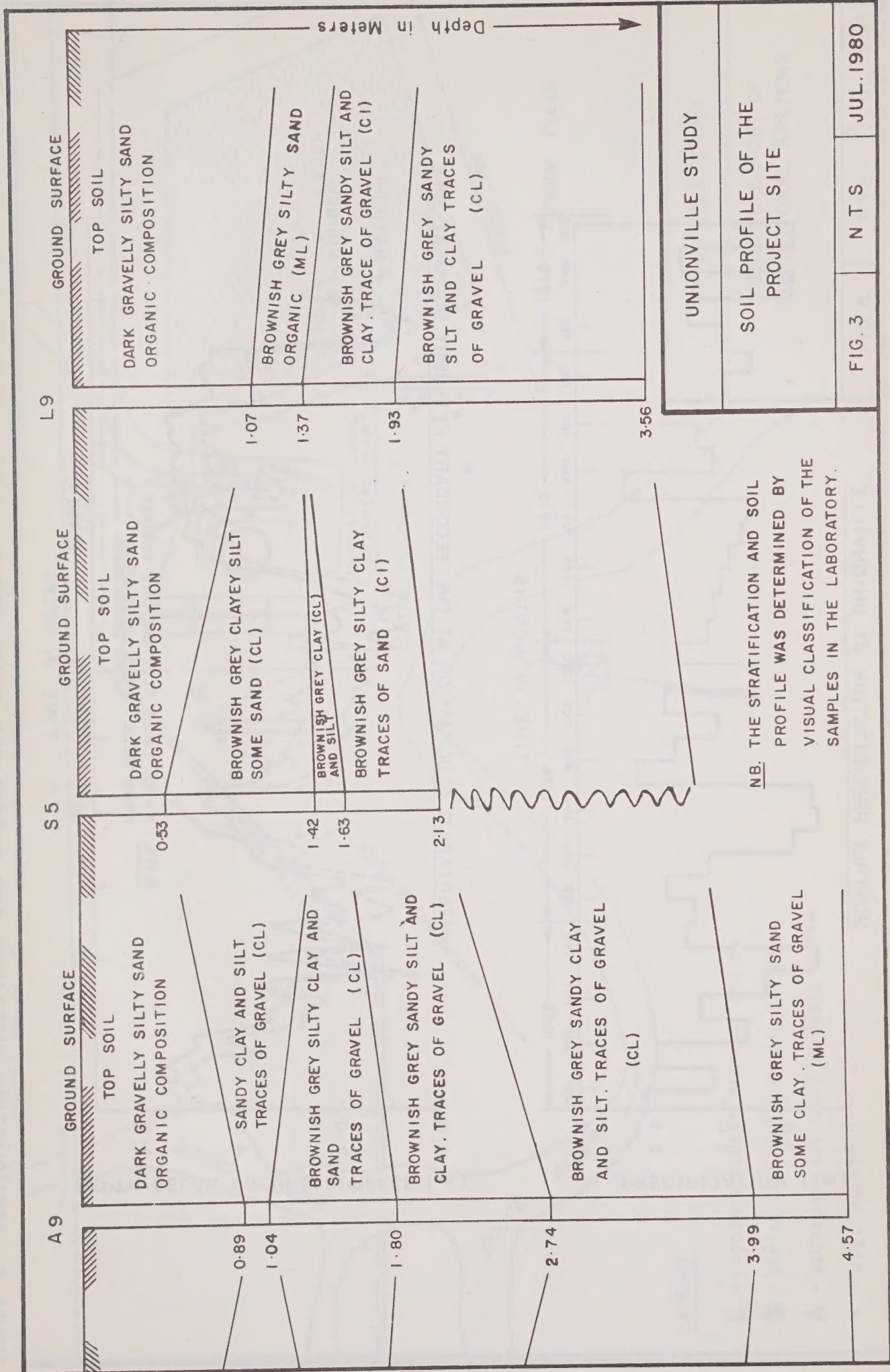
TABLE 14

PERCENTAGE REMOVAL OF CONTAMINANTS BY TEST COLUMNS

CONTAMINANTS * AND OTHER PARAMETERS	SEPTIC TANK EFFLUENT FEED			POLISHING LAGOON EFFLUENT FEED			PLANT'S SECONDARY EFFLUENT FEED		
	Before Percolation	After Percolation (Col.1, 2, 3) Average	Removal (%)	Before Percolation	After Percolation (Col.4, 5, 6) Average	Removal (%)	Before Percolation	After Percolation (Col.7, 8, 9) Average	Removal (%)
pH	7.54	8.02	-	7.84	8.1	-	7.52	8.08	-
BOD ₅	38.3	1.02	97.33	19.7	0.69	96.5	23.4	0.83	96.5
Total Solids	1242	1185	4.6	899.6	898.5	0.12	1007	932.6	7.4
Suspended Solids	30	<5	>80	19.3	<5	>70	18.5	<5	>70
Total Nitrogen (as N)	28.97	11.06	61.8	18.3	1.30	92.9	24.4	1.07	95.6
Total Phosphorus (as P)	6.9	<0.02	>99.5	5.6	<0.02	>99.5	5.5	<0.02	>99.5
Sodium (as Na)	267	243.9	8.7	189.7	193.1	1.8 +	214.9	167	22.3
Potassium (as K)	14.8	1.6	88.7	11.5	3.57	70	11.4	2.17	80.9
Chlorides (as Cl)	428.8	428	0.2	269	324.6	20.7 +	321.6	395.9	23.1 +
Calcium (As Ca)	103.9	125.9	21.2 +	84.2	114.3	35.8 +	91.9	125.6	36.7 +
Sulphates (SO ₄)	65.5	67.5	3.1 +	68.6	45.5	33.6	72.5	39.5	45.6
Hardness (as CaCO ₃)	397.3	399.8	0.6 +	315	370.6	17.9 +	338.5	400.5	18.3 +
Alkalinity (as CaCO ₃)	398.1	223.1	44.0	309	273.5	11.5	321.4	228.6	28.9
Conductivity (as µmho/cm)	2254	2067	8.3	1620	1721	6.2 +	2031	1927	5.1



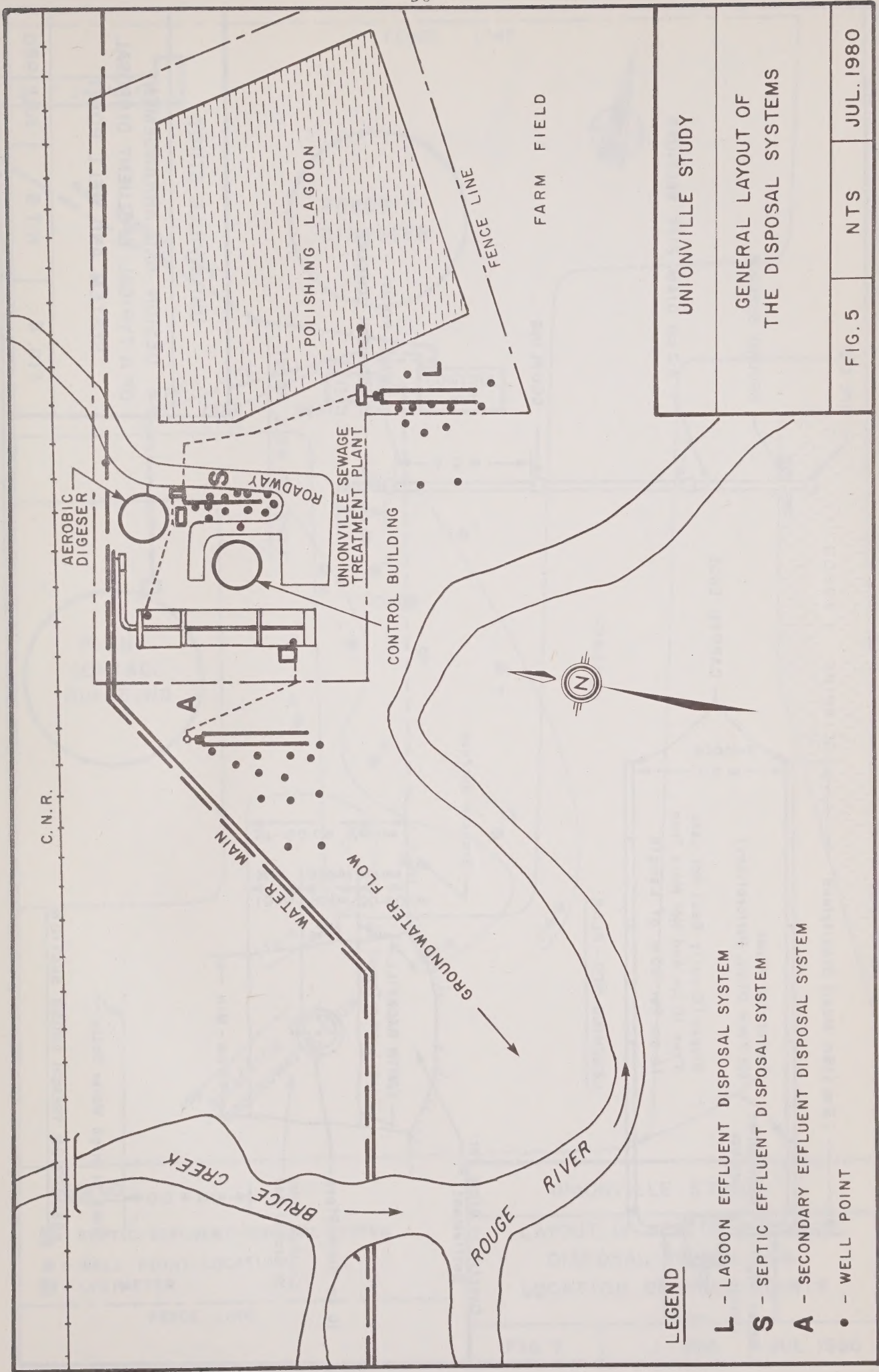


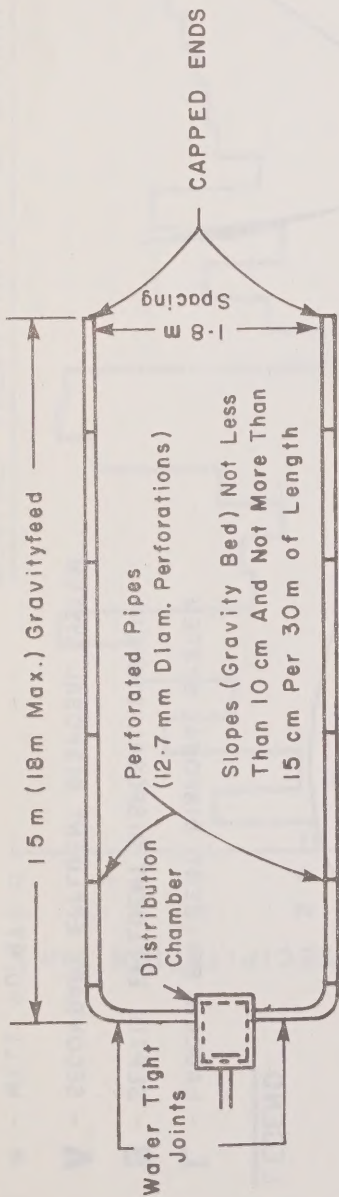


NB. THE STRATIFICATION AND SOIL PROFILE WAS DETERMINED BY VISUAL CLASSIFICATION OF THE SAMPLES IN THE LABORATORY.

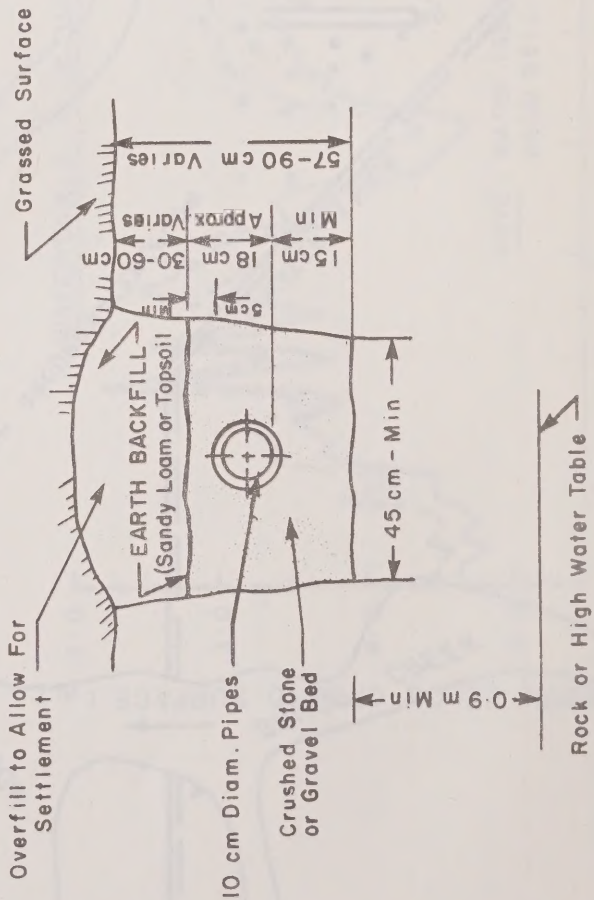
UNIONVILLE STUDY

SOIL PROFILE OF THE PROJECT SITE

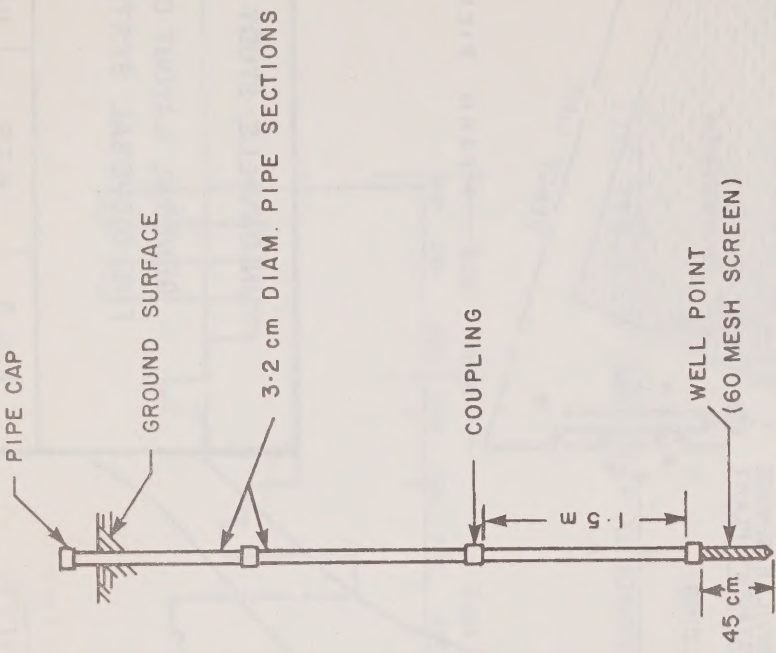




LEACHING BED - PLAN

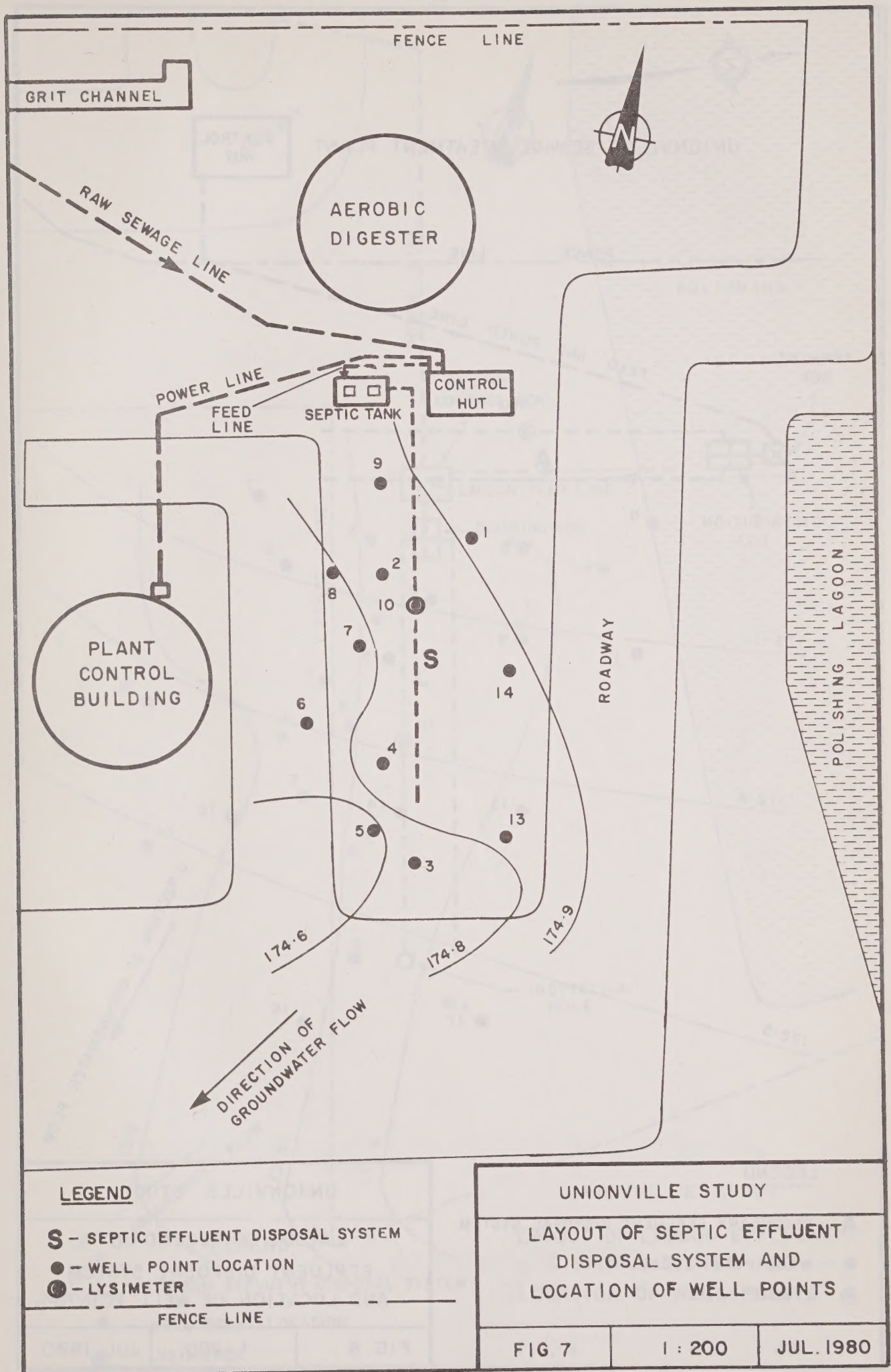


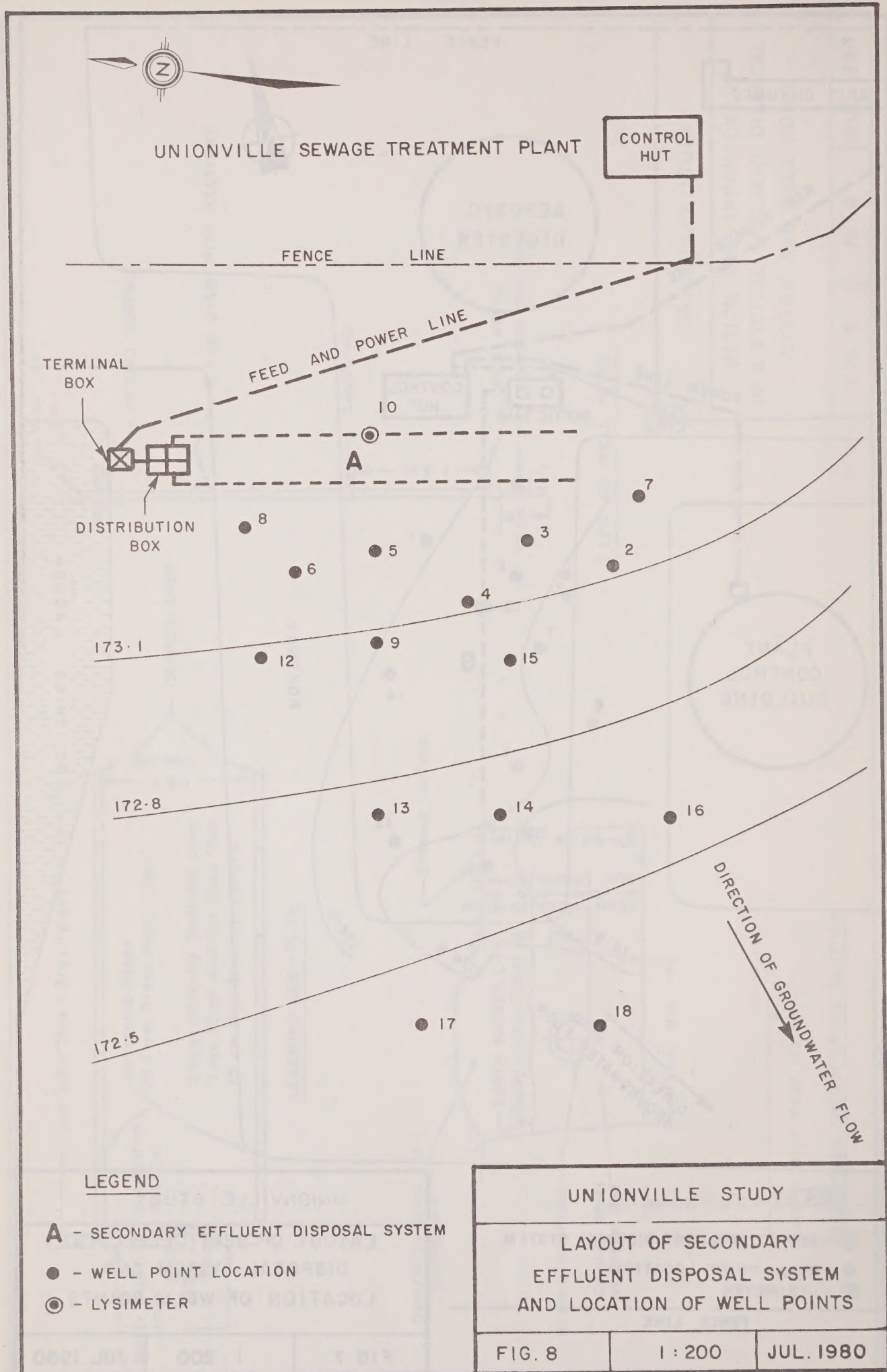
ABSORPTION TRENCH CROSS SECTION



TYPE OF WELL POINT

UNIONVILLE STUDY		
DESIGN AND ARRANGEMENT OF A TYPICAL EFFLUENT DISPOSAL SYSTEM AND WELL POINT		
FIG. 6	NTS	JUL. 1980





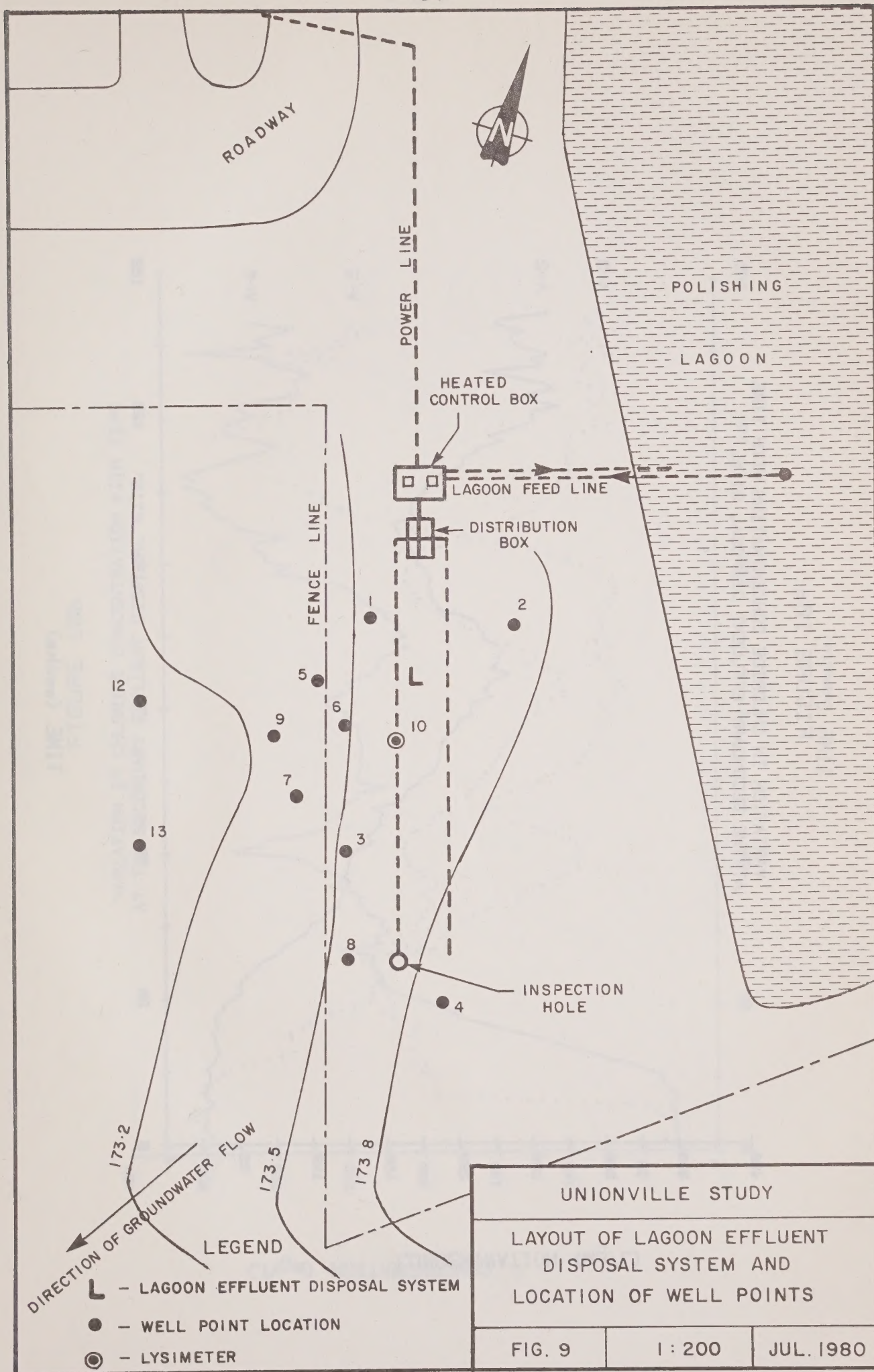


FIGURE 10a

VARIATION IN CHLORIDE CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE.

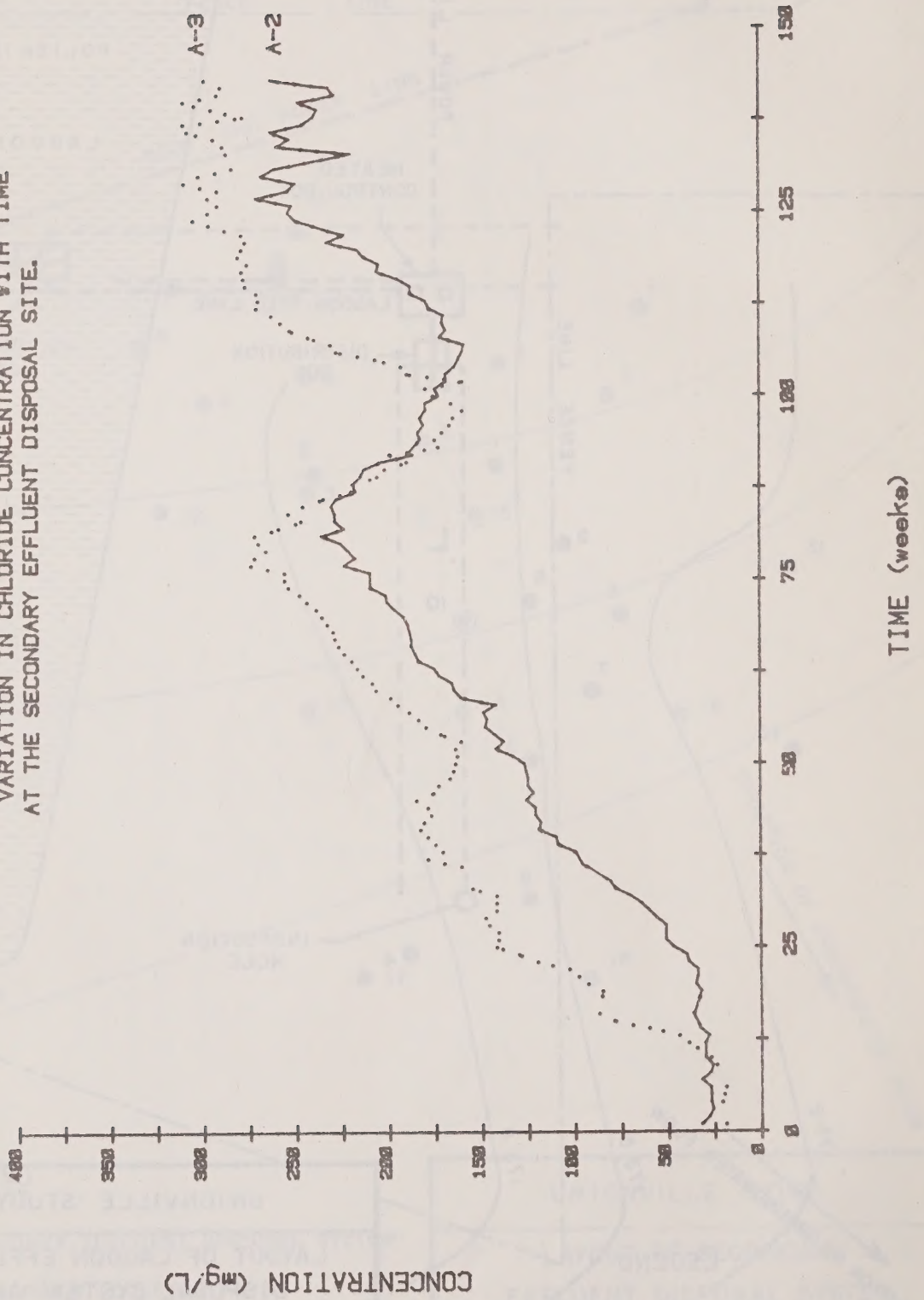


FIGURE 10b

VARIATION IN CHLORIDE CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE.

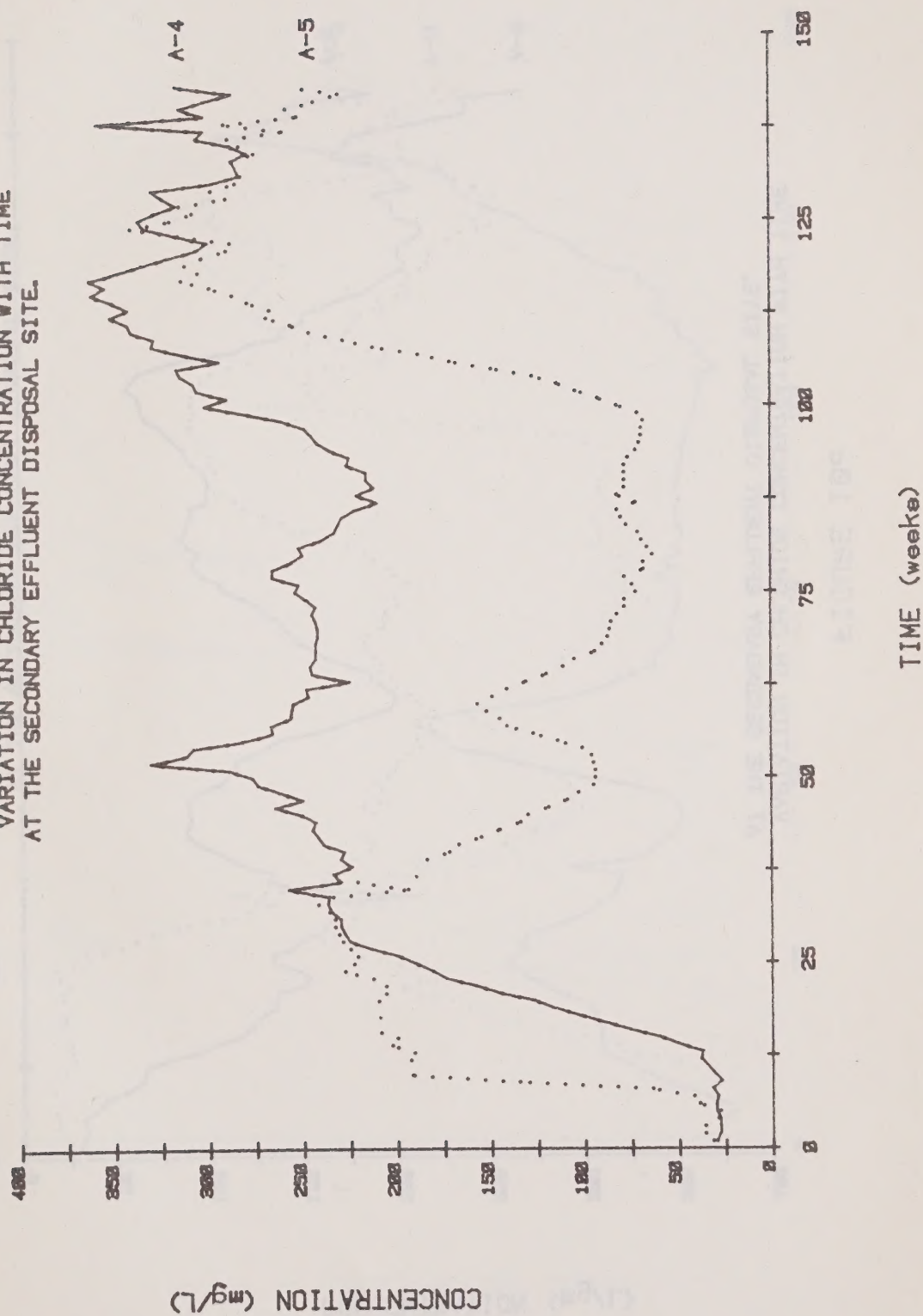


FIGURE 10c

VARIATION IN CHLORIDE CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE.

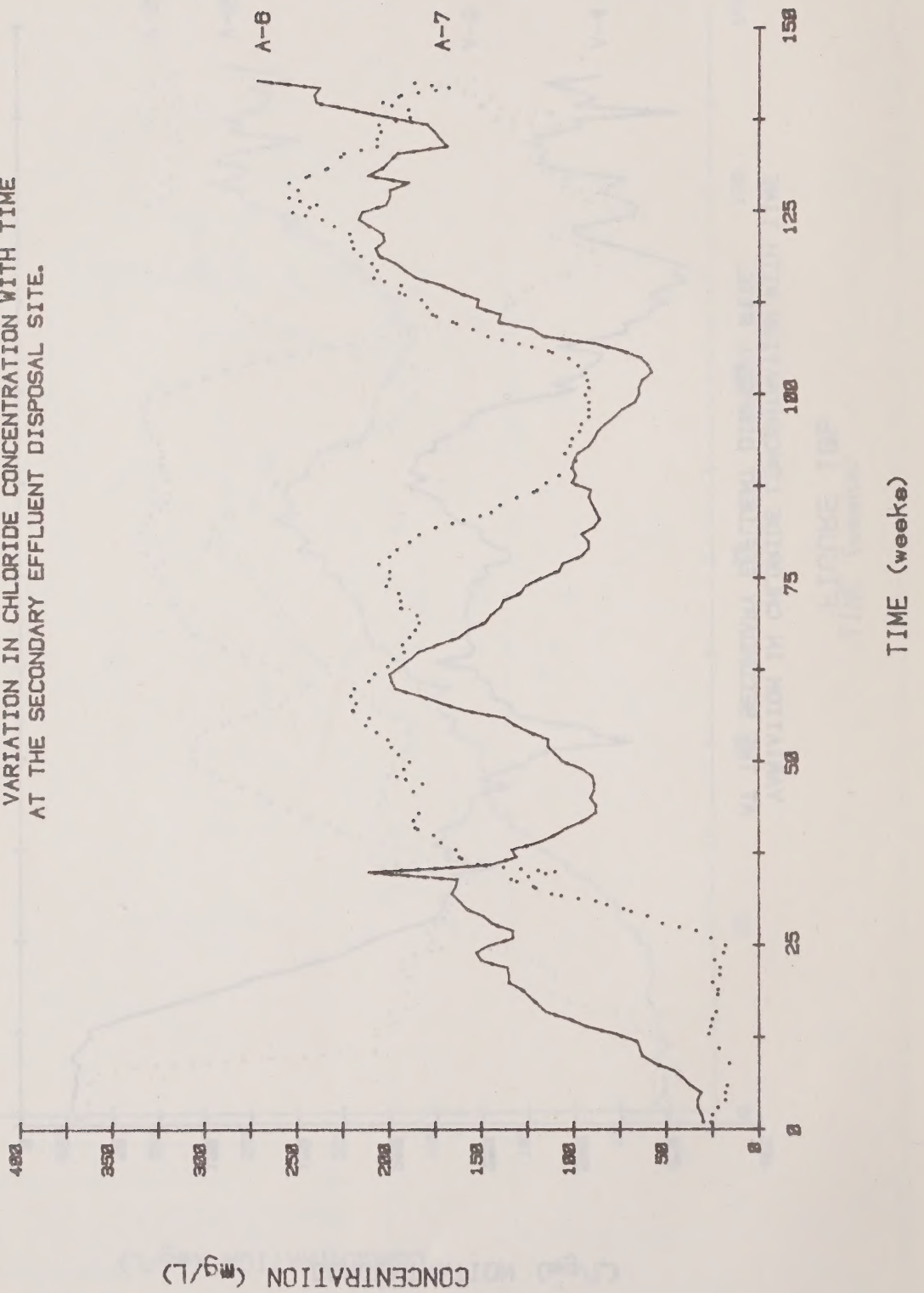


FIGURE 10d
VARIATION IN CHLORIDE CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE.

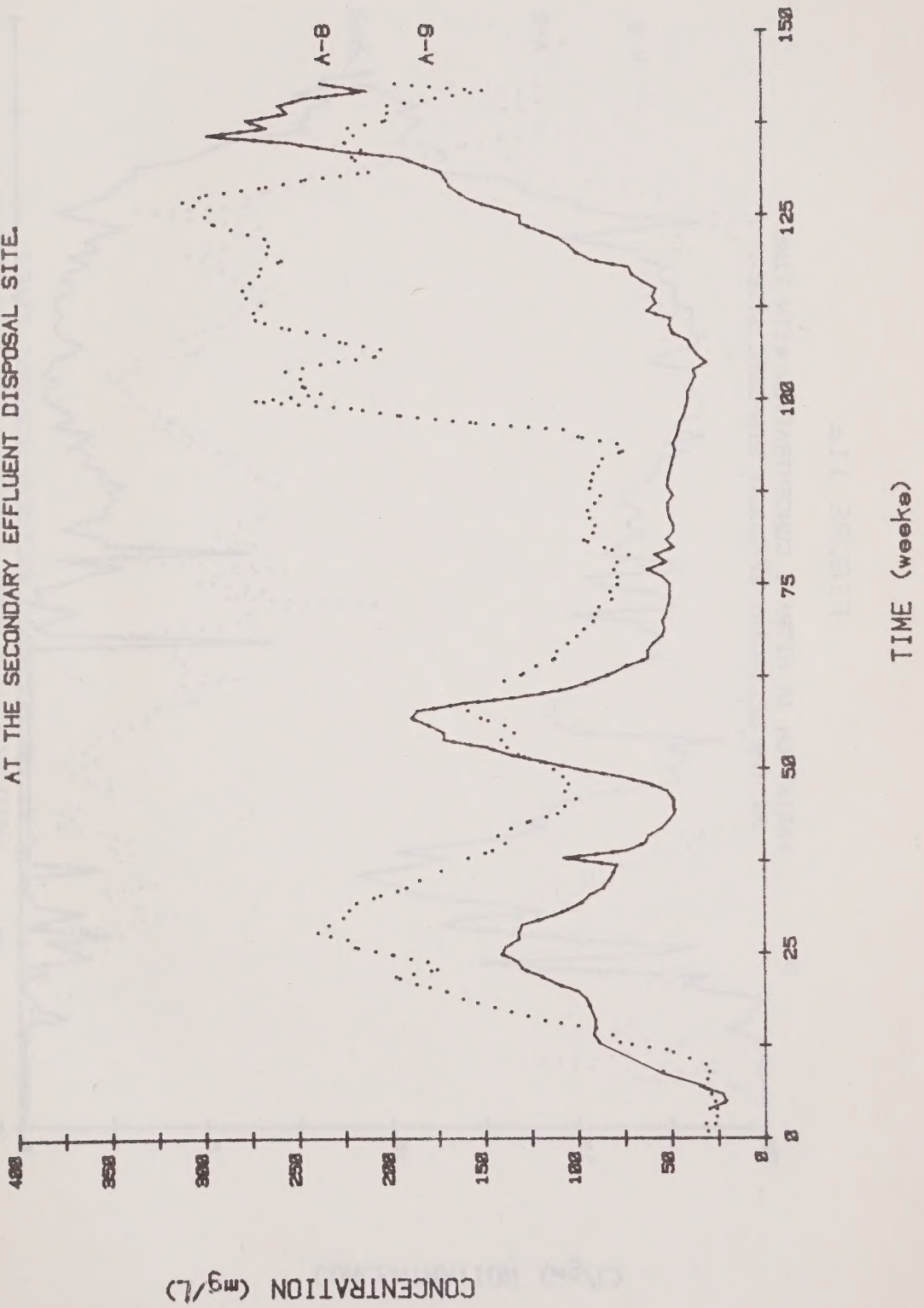
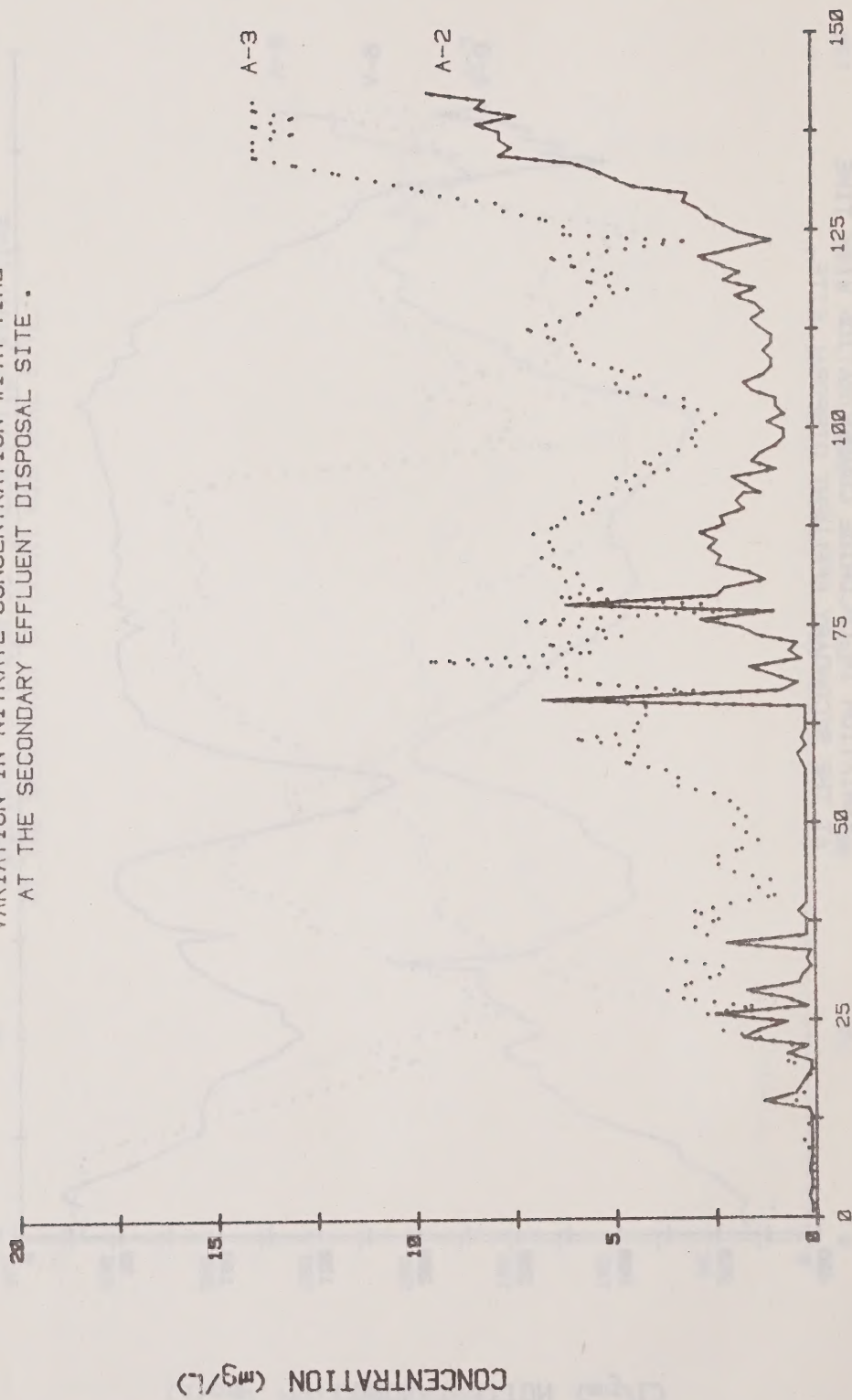


FIGURE 11a

VARIATION IN NITRATE CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE.



TIME (weeks)

FIGURE 11b

VARIATION IN NITRATE CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE .

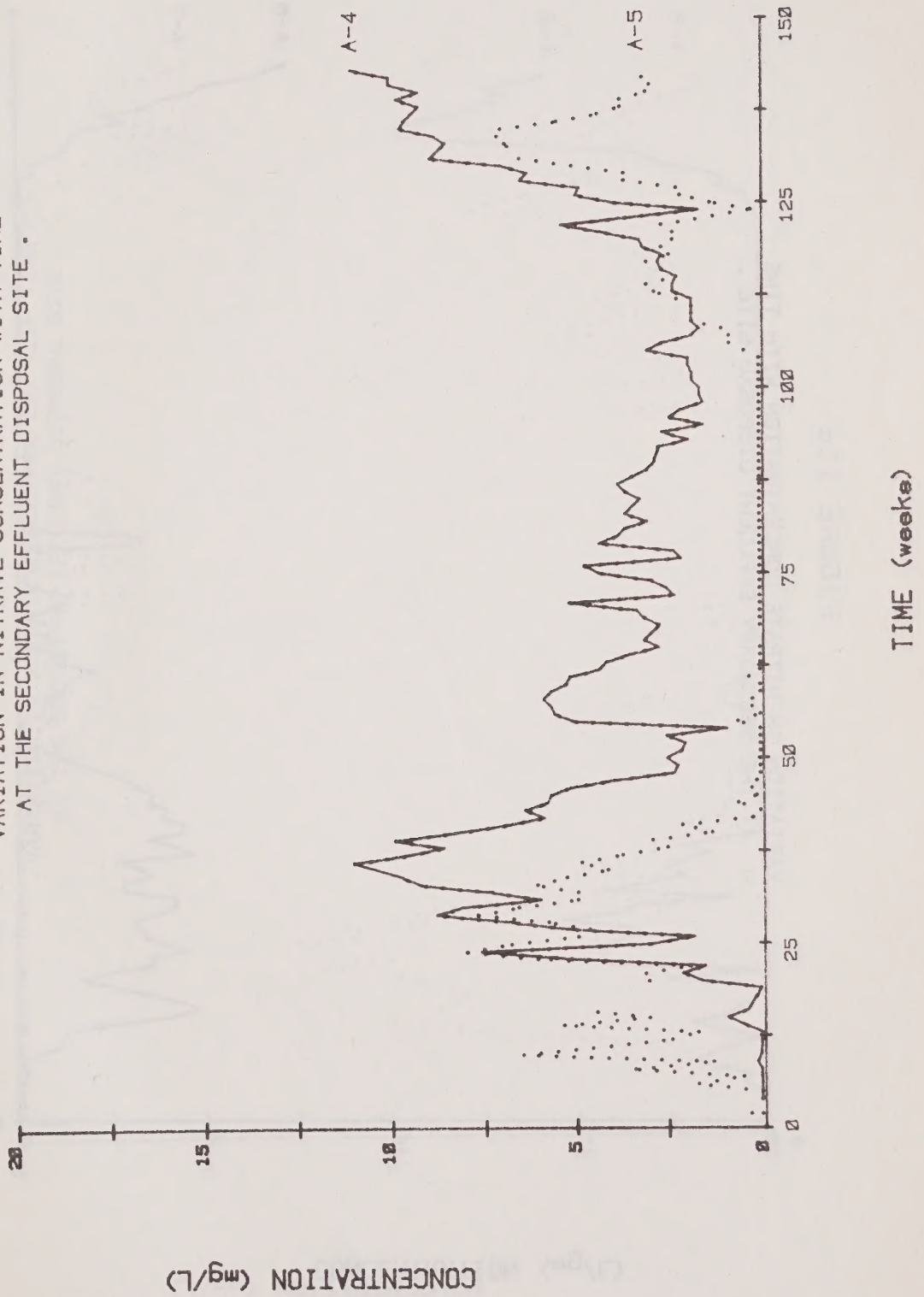
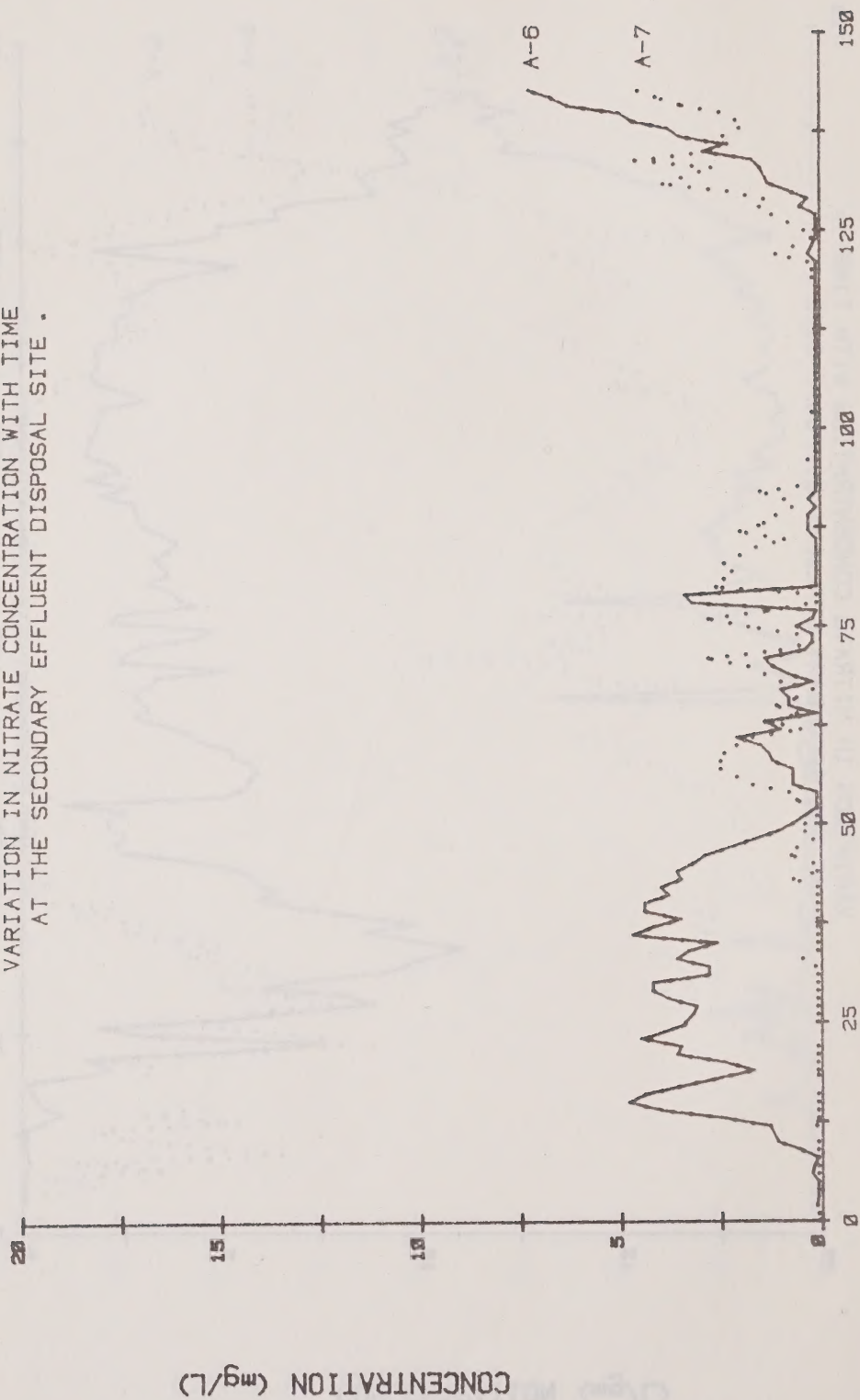


FIGURE 11c

VARIATION IN NITRATE CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE .



TIME (weeks)

FIGURE 11d

VARIATION IN NITRATE CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE .

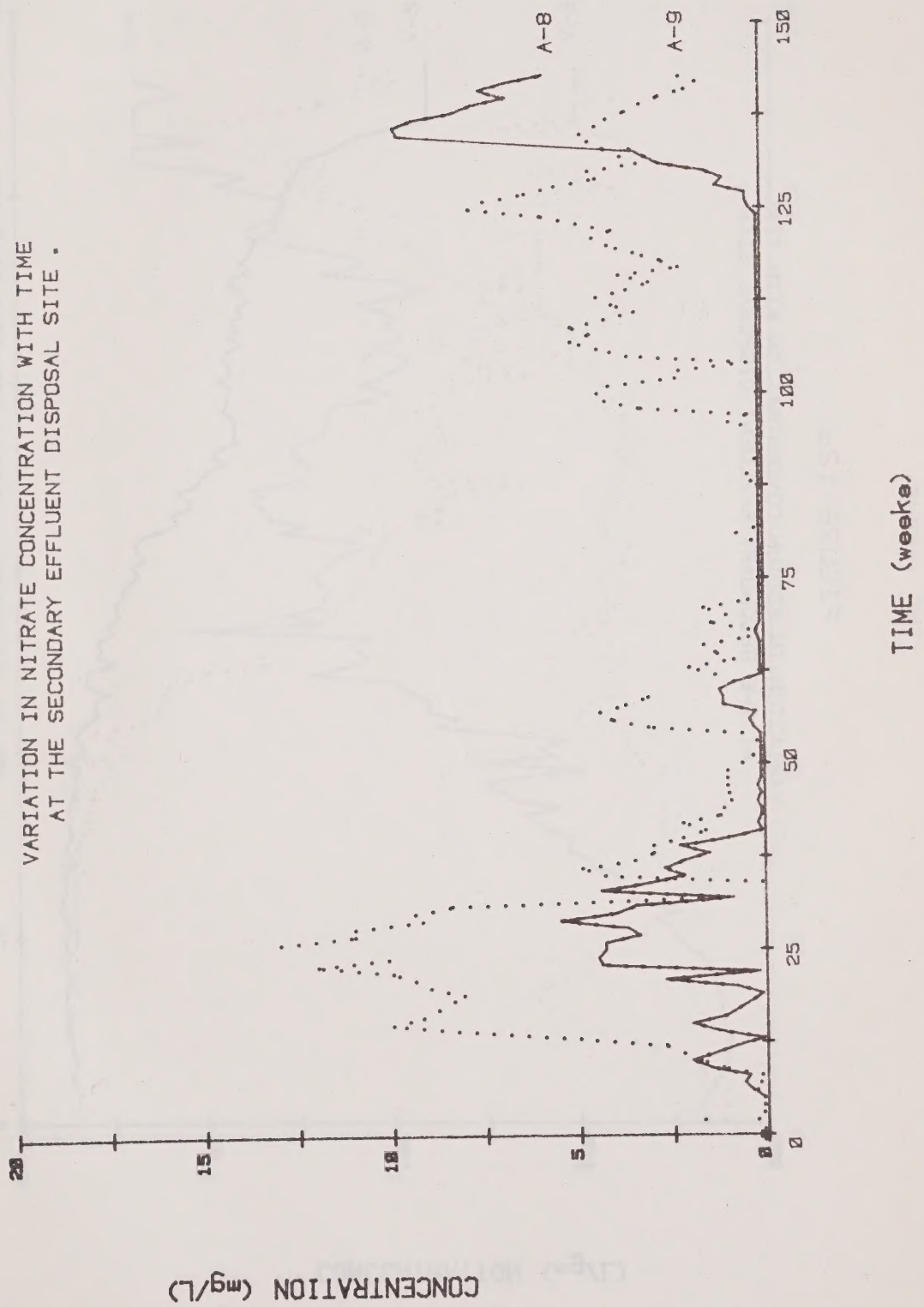
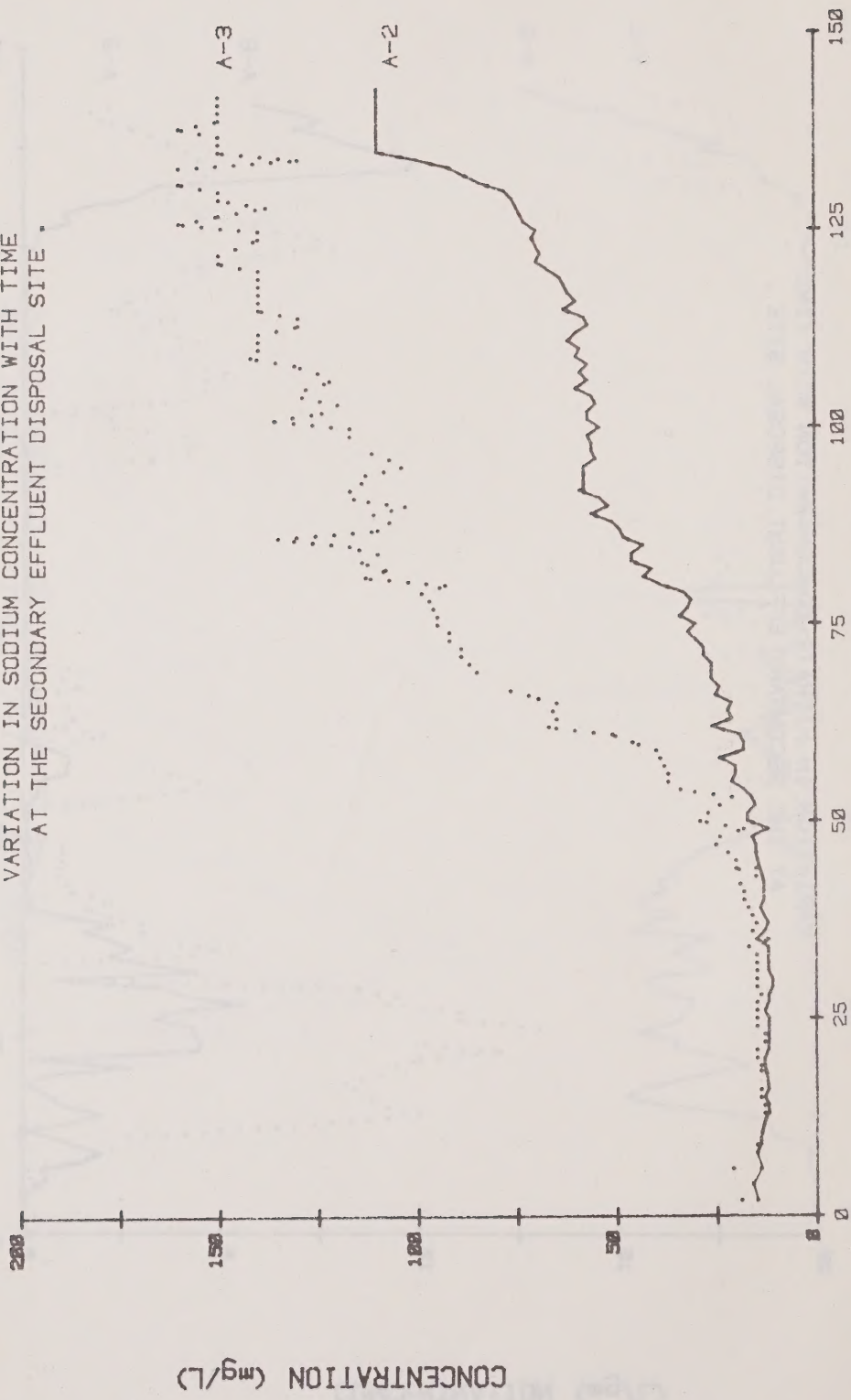


FIGURE 12a

VARIATION IN SODIUM CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE .



TIME (weeks)

FIGURE 12b

VARIATION IN SODIUM CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE .

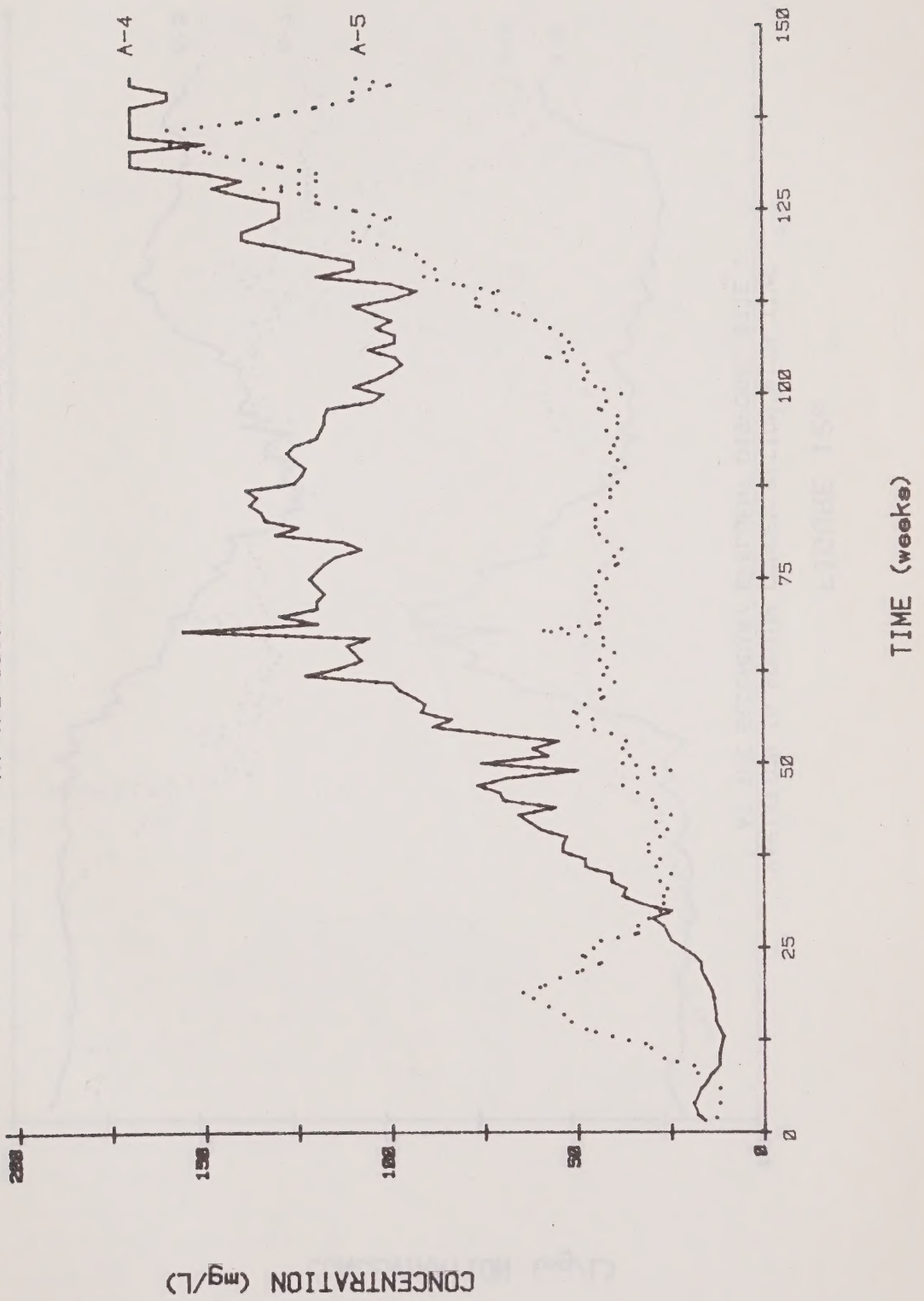


FIGURE 12c

VARIATION IN SODIUM CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE .

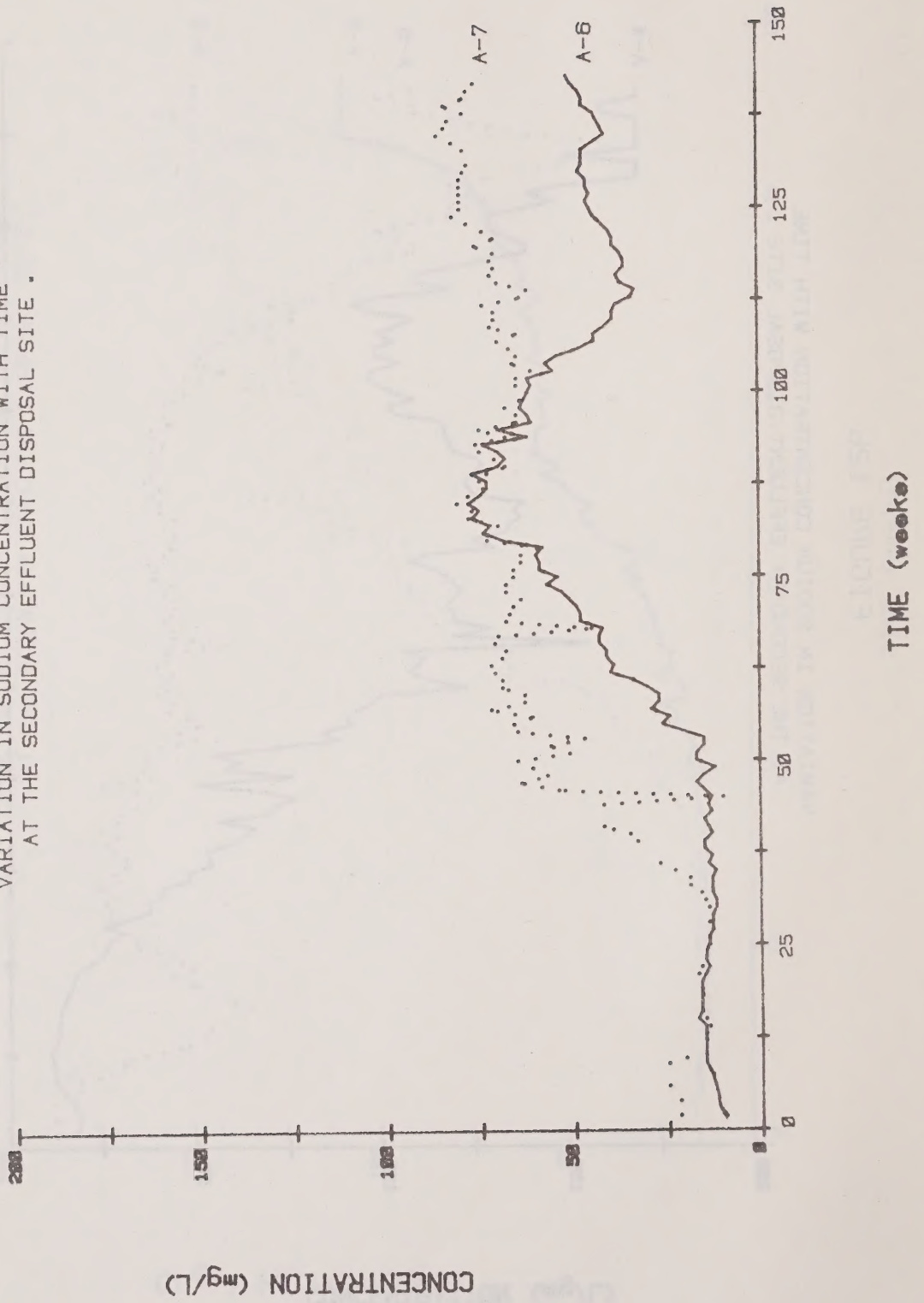
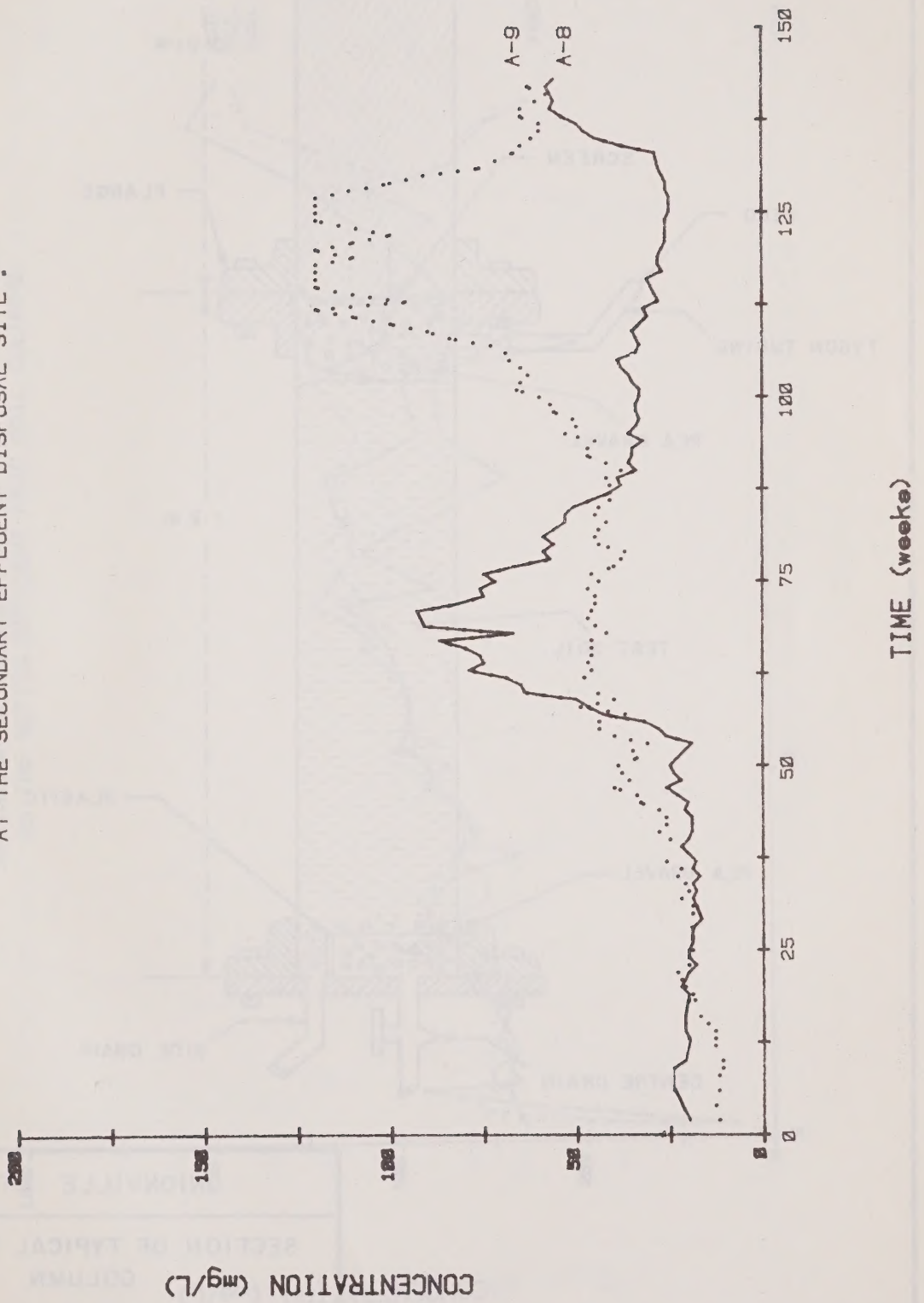
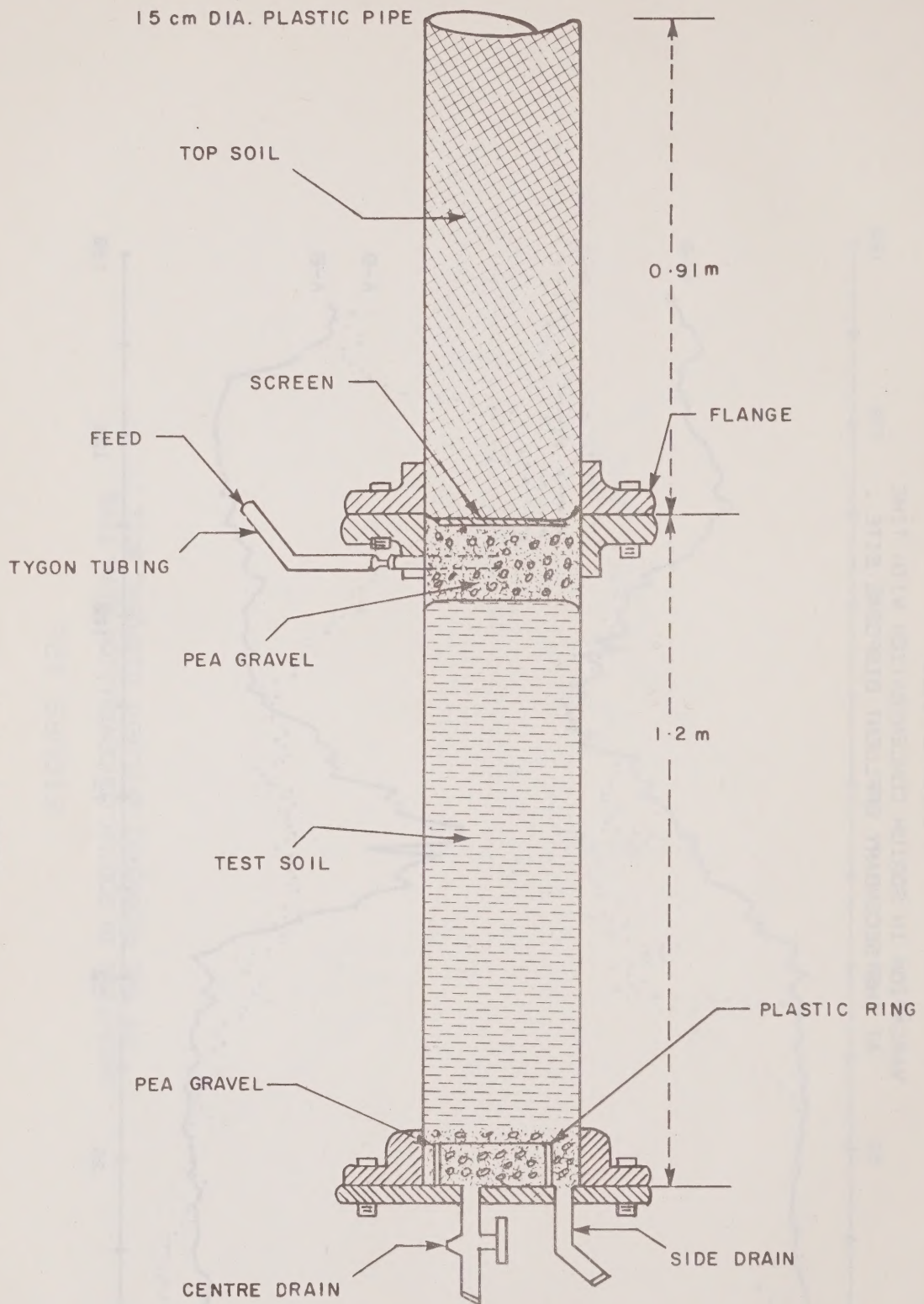


FIGURE 12d
VARIATION IN SODIUM CONCENTRATION WITH TIME
AT THE SECONDARY EFFLUENT DISPOSAL SITE .





UNIONVILLE STUDY

SECTION OF TYPICAL TEST SOIL COLUMN

FIG. 13

1 : 11.5
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JUL. 1980

FIGURE 14a

VARIAION OF CHLORIDE CONCENTRATION WITH TIME
IN THE SEPTIC EFFLUENT FEED SOIL COLUMNS.

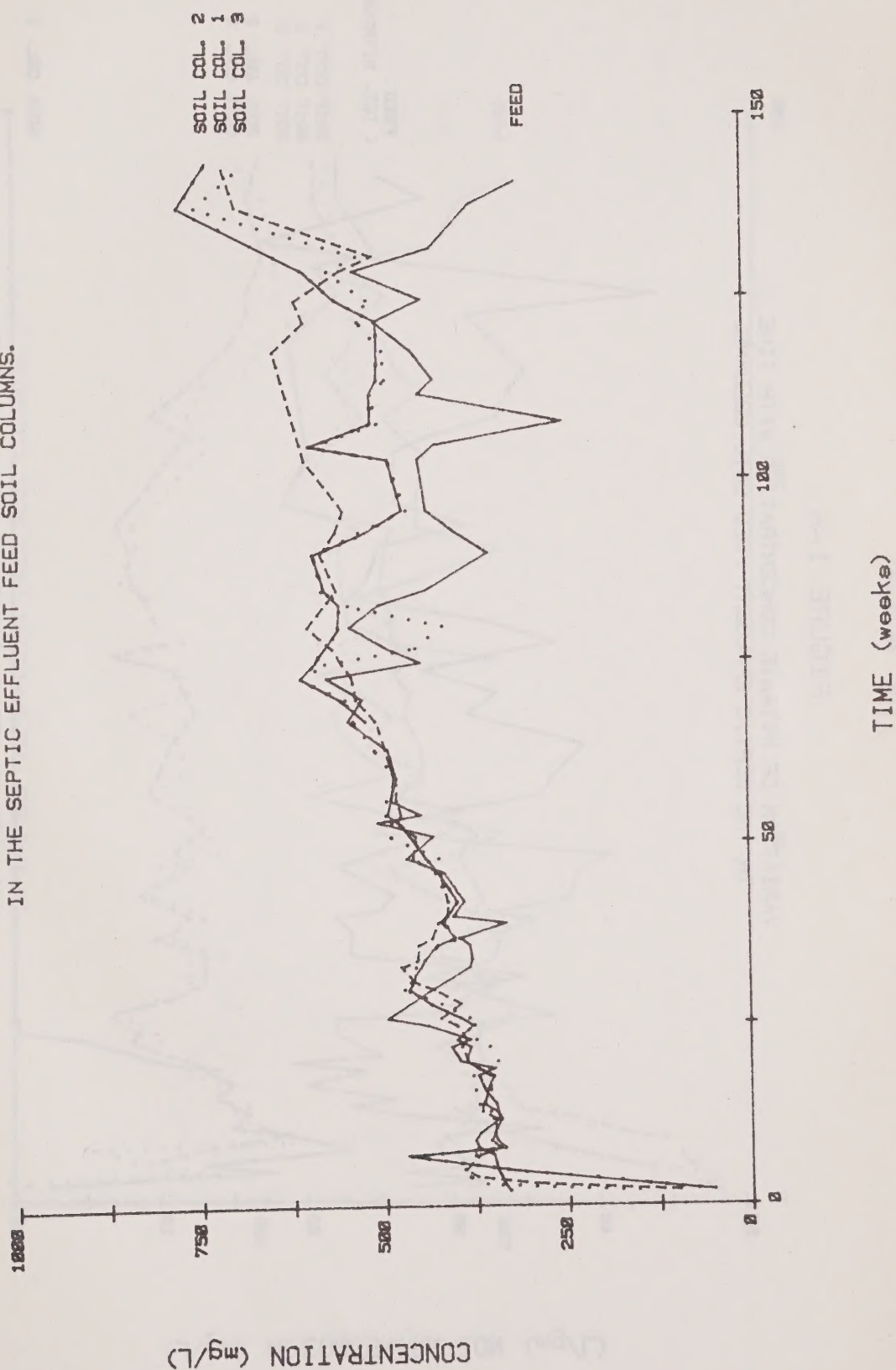


FIGURE 14b

VARIATION OF NITRATE CONCENTRATION WITH TIME
IN THE SEPTIC EFFLUENT FEED SOIL COLUMNS.

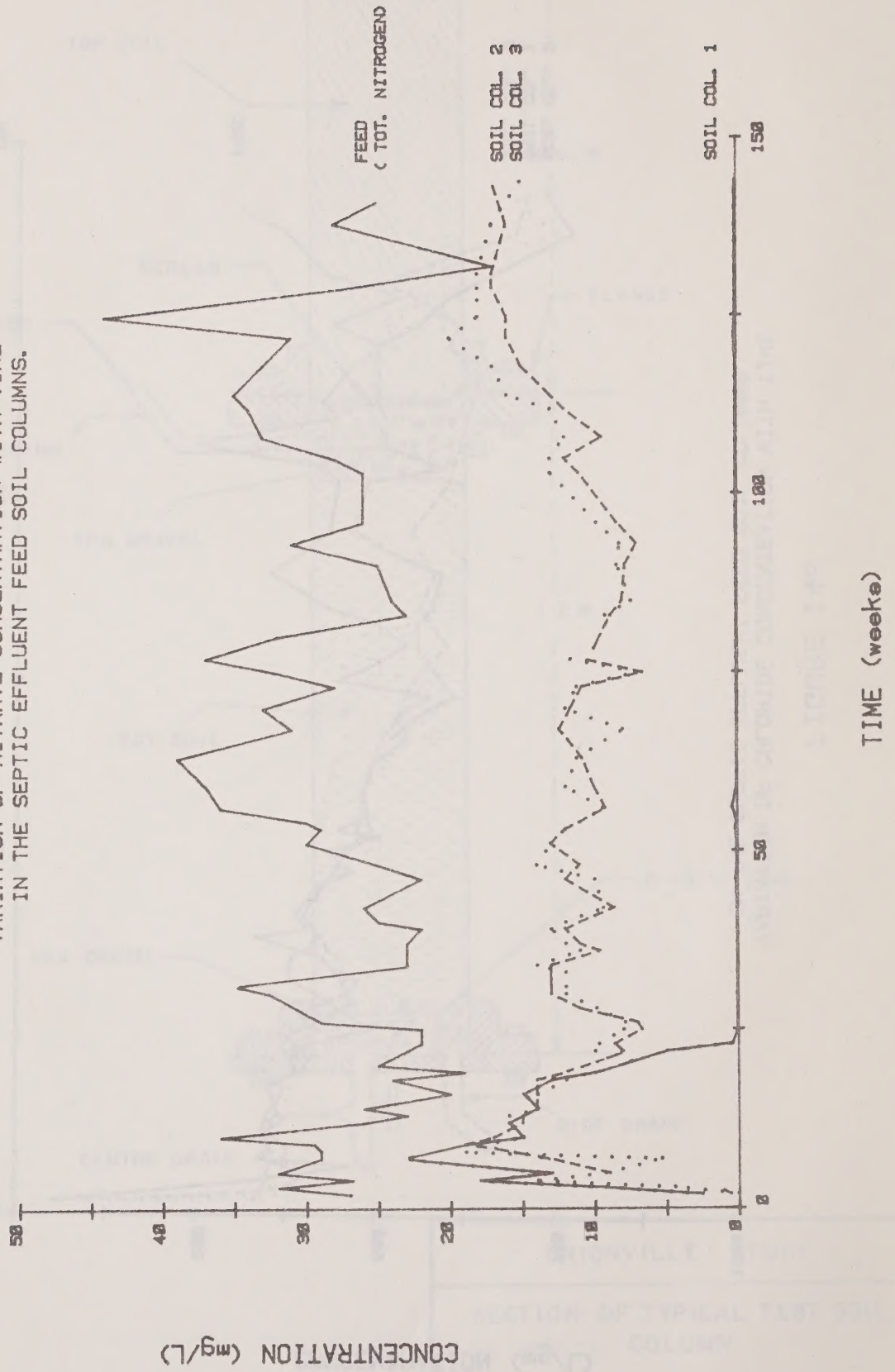


FIGURE 14c

VARIATION OF SODIUM CONCENTRATION WITH TIME
IN THE SEPTIC EFFLUENT FEED SOIL COLUMNS.

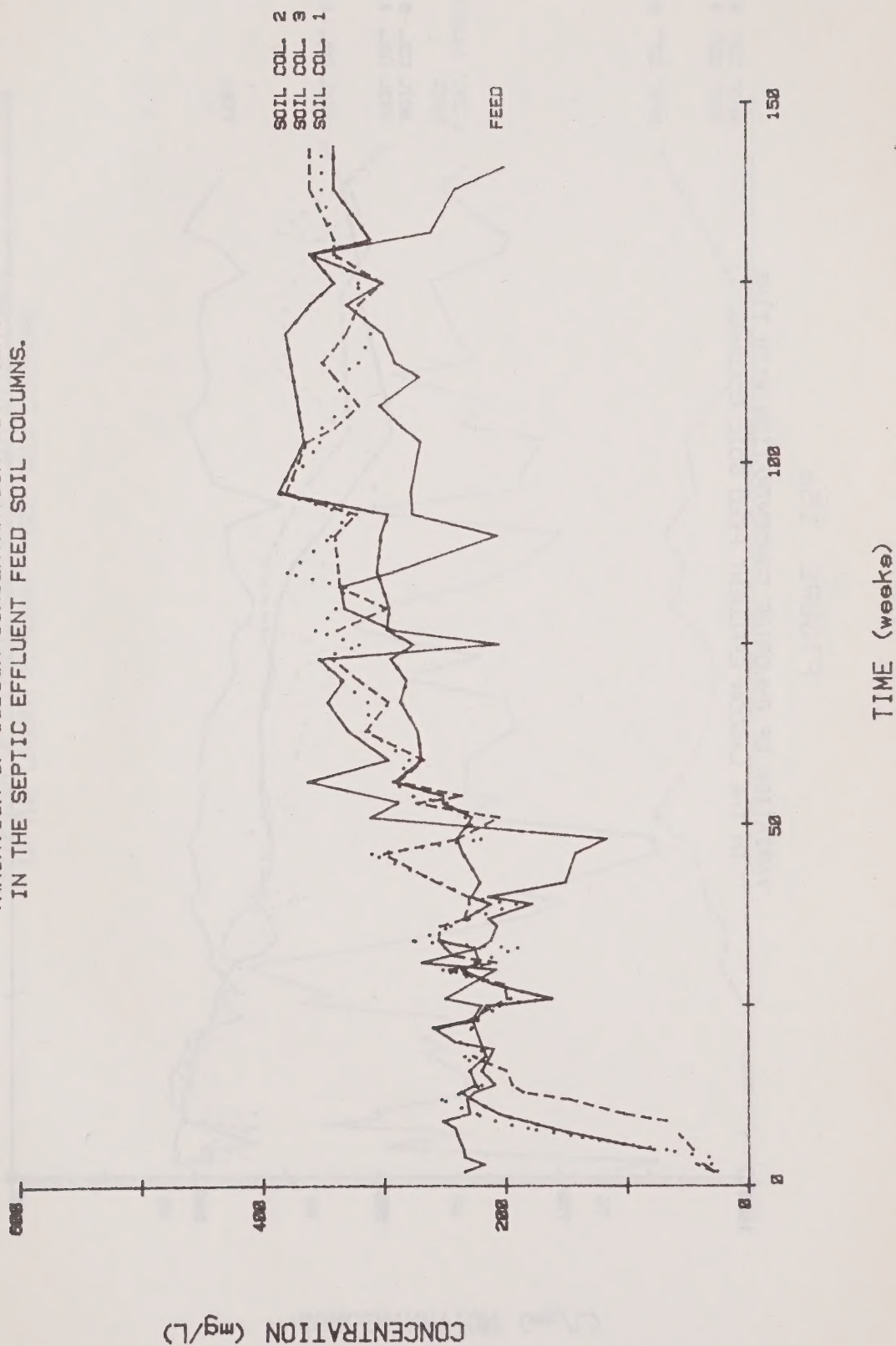


FIGURE 15a

VARIATION OF CHLORIDE CONCENTRATION WITH TIME
IN THE LAGOON EFFLUENT FEED SOIL COLUMNS.

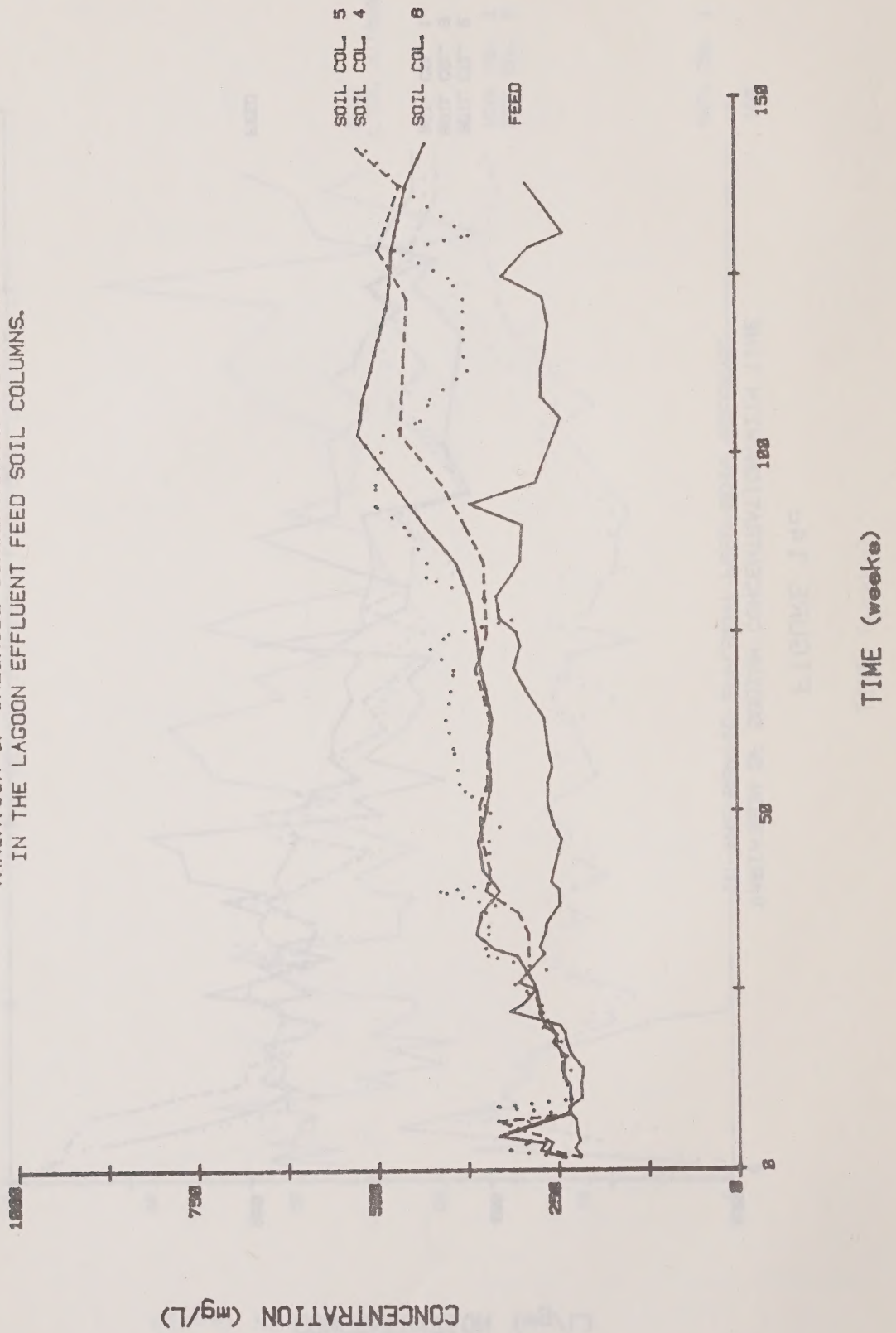


FIGURE 15b

VARIATION OF NITRATE CONCENTRATION WITH TIME
IN THE LAGOON EFFLUENT FEED SOIL COLUMNS.

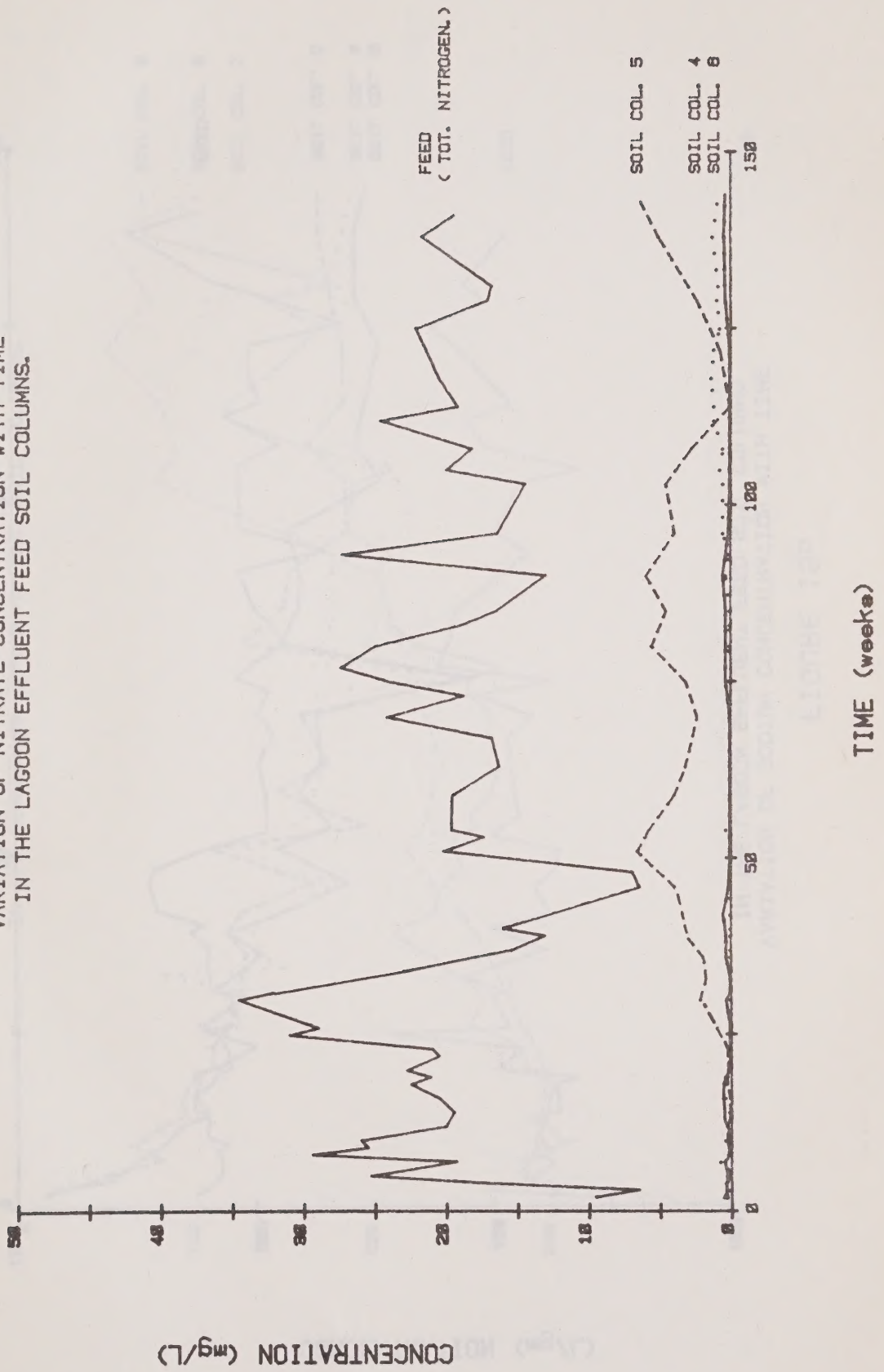


FIGURE 15c

variation of sodium concentration with time
in the lagoon effluent feed soil columns.

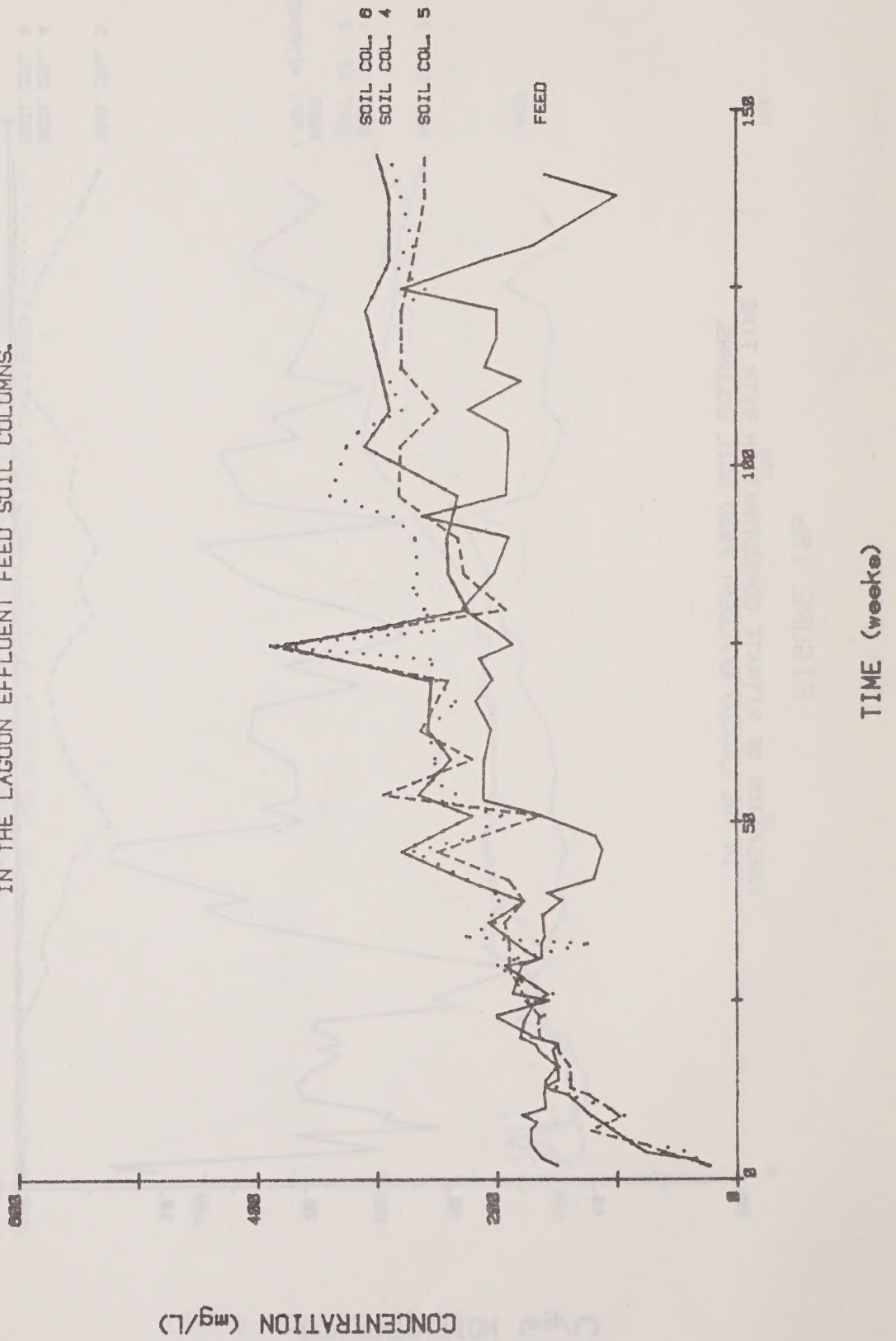


FIGURE 16a

VARIATION OF CHLORIDE CONCENTRATION WITH TIME
IN THE SECONDARY EFFLUENT FEED SOIL COLUMNS.

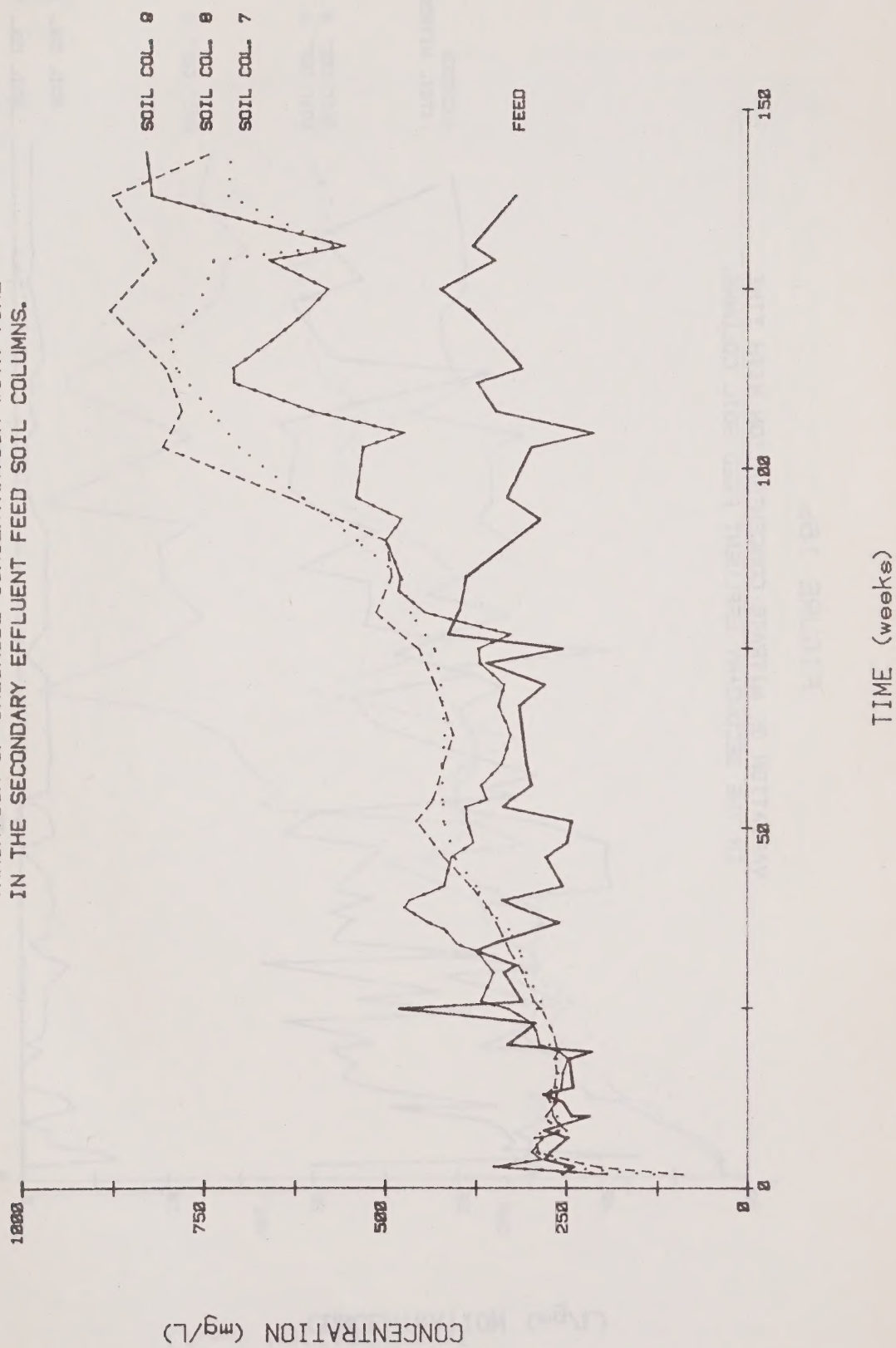


FIGURE 16b

VARIATION OF NITRATE CONCENTRATION WITH TIME
IN THE SECONDARY EFFLUENT FEED SOIL COLUMNS.

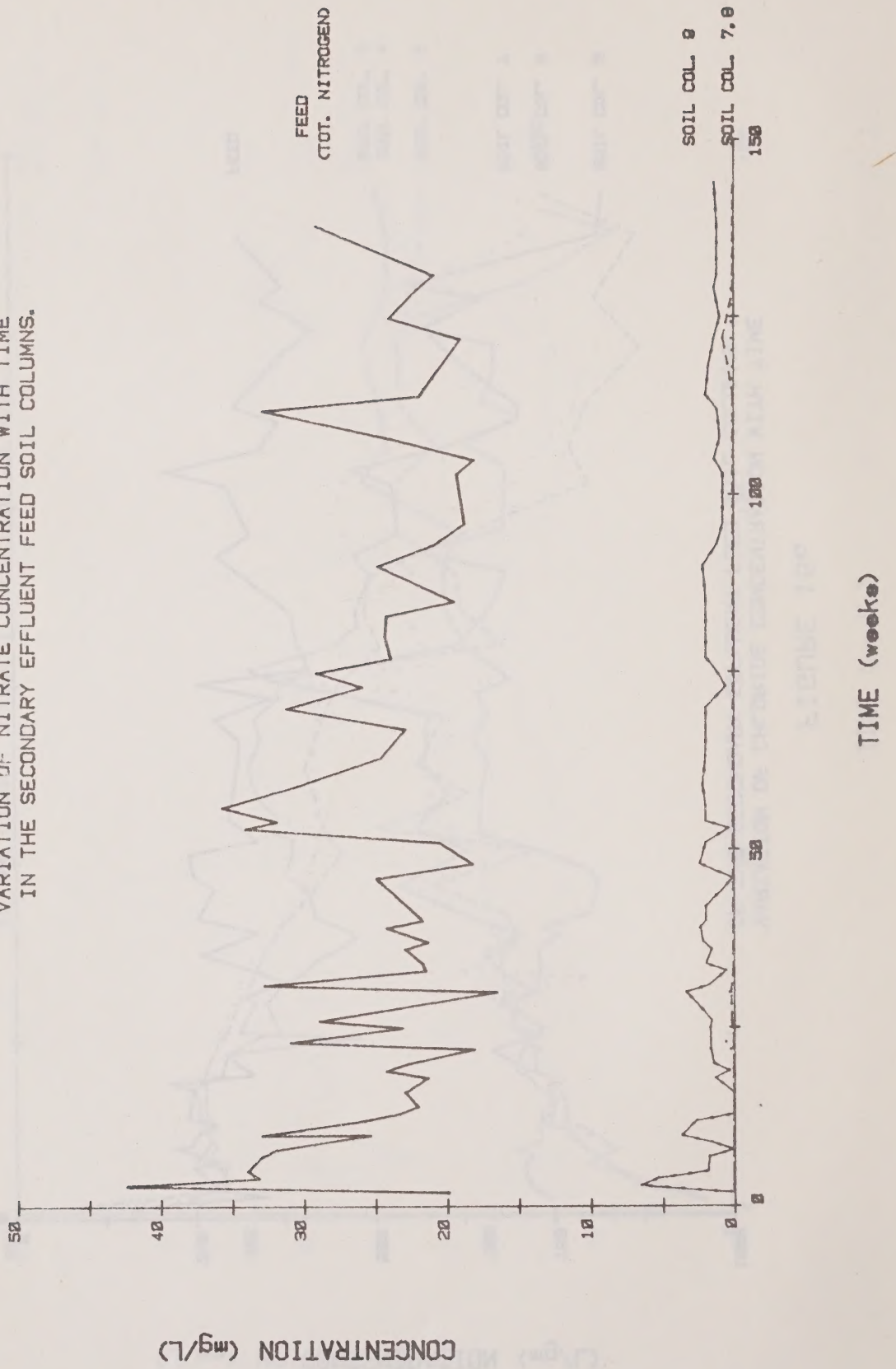
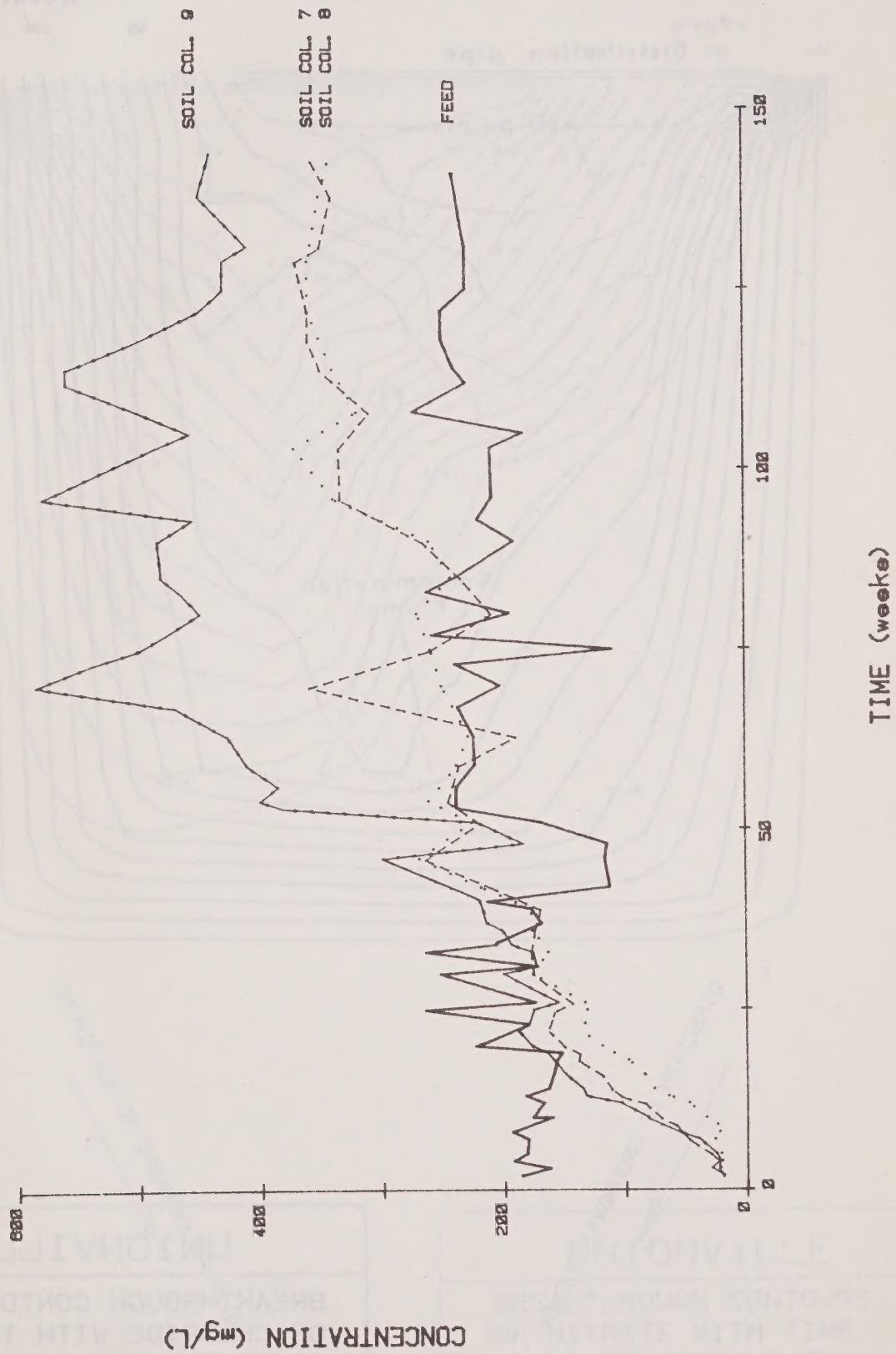
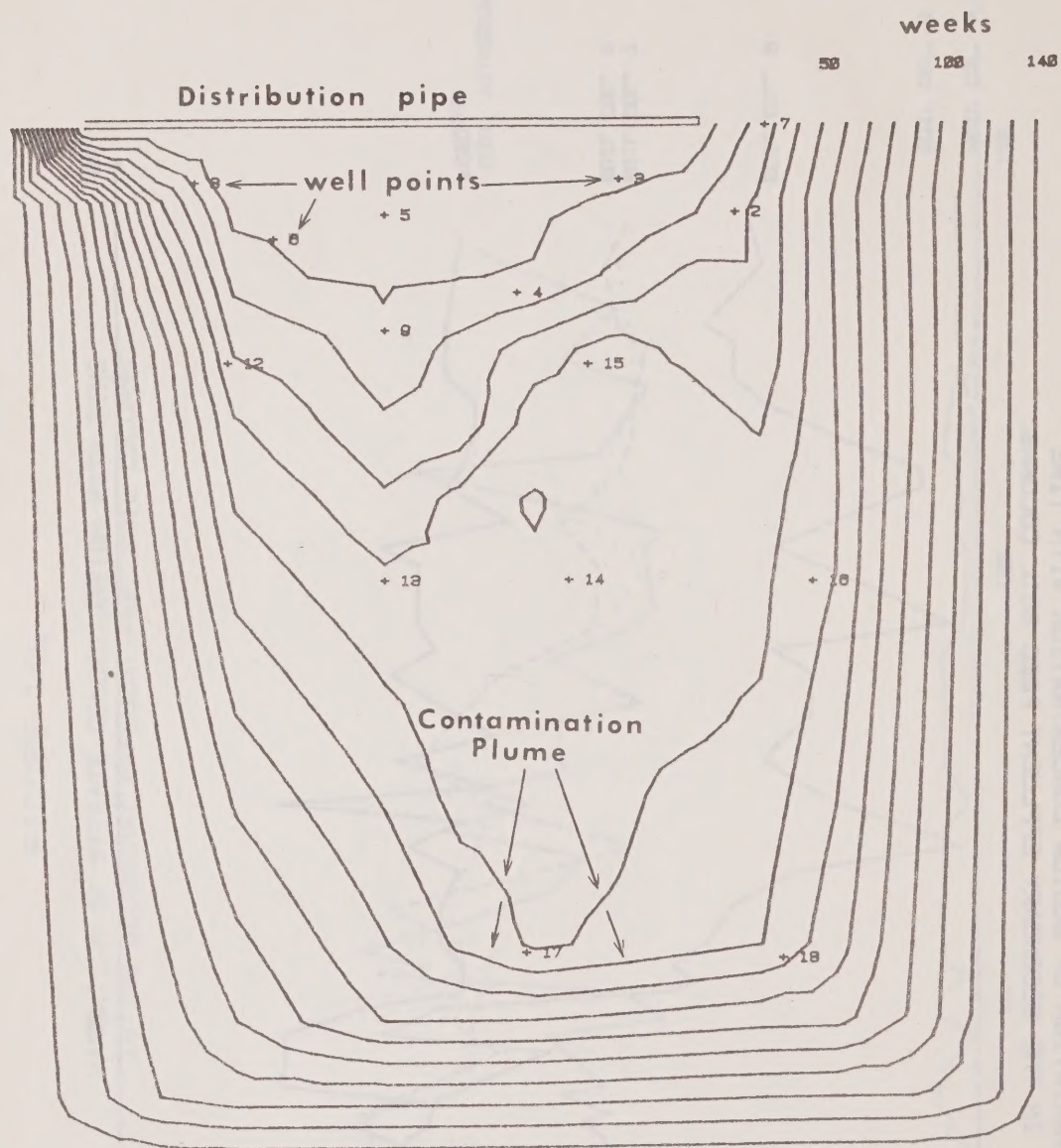


FIGURE 16c

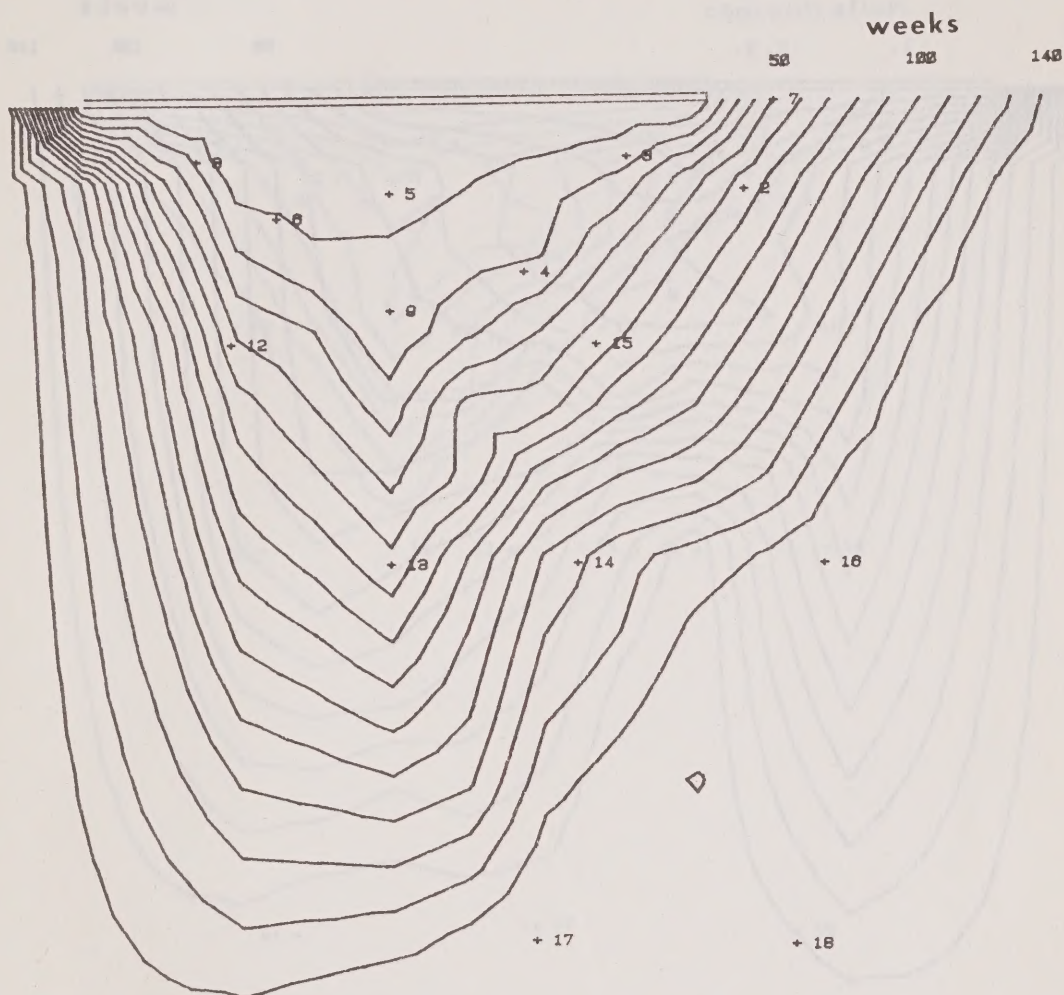
VARIATION OF SODIUM CONCENTRATION WITH TIME
IN THE SECONDARY EFFLUENT FEED SOIL COLUMNS.





DIRECTION OF GROUNDWATER FLOW

UNIONVILLE		
BREAKTHROUGH CONTOURS OF CHLORIDE WITH TIME CONCENTRATION LEVEL $C/C_0 = 0.1$		
FIG 17	1: 188	JULY1980



DIRECTION OF GROUNDWATER FLOW

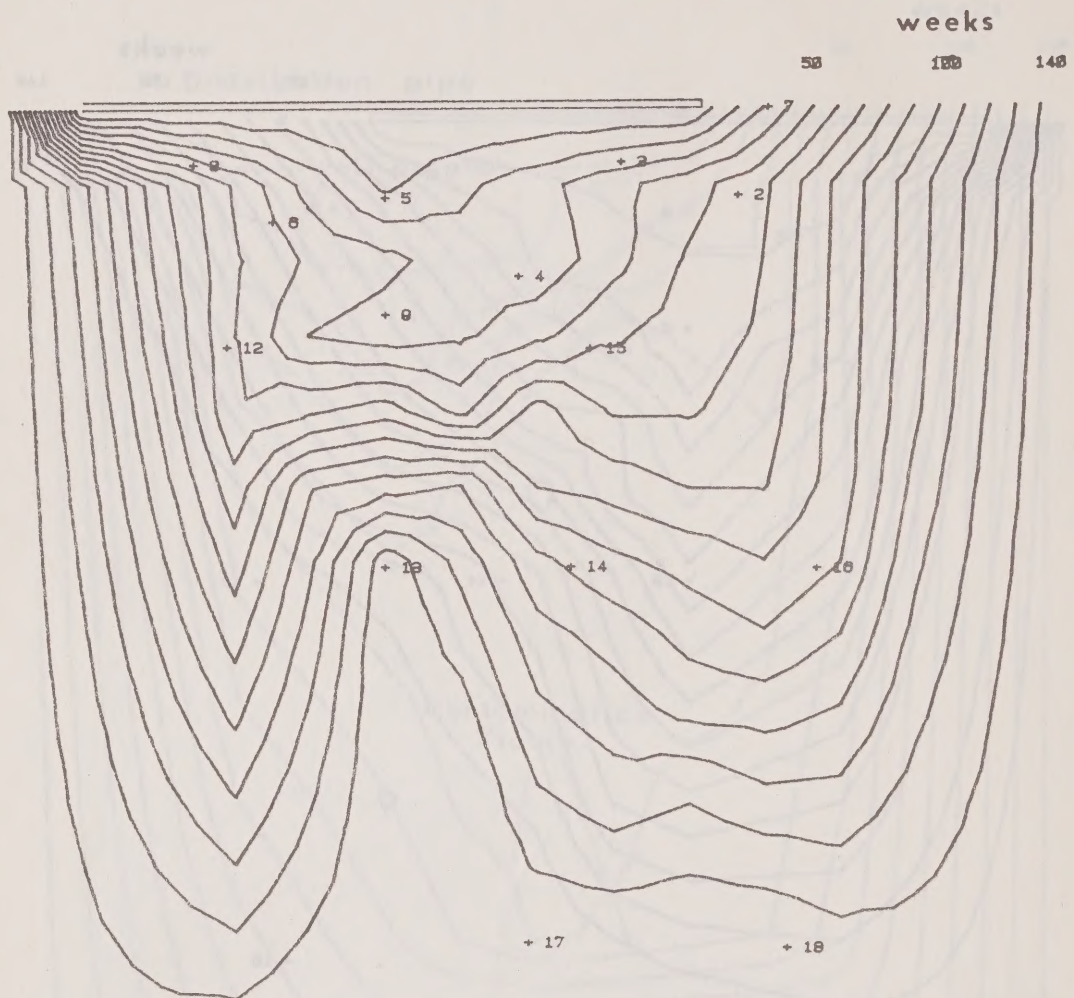
UNIONVILLE

BREAKTHROUGH CONTOURS
OF NITRATE WITH TIME
CONCENTRATION LEVEL
 $C/C_0 = 0.1$

FIG 18

1: 188

JULY 1980

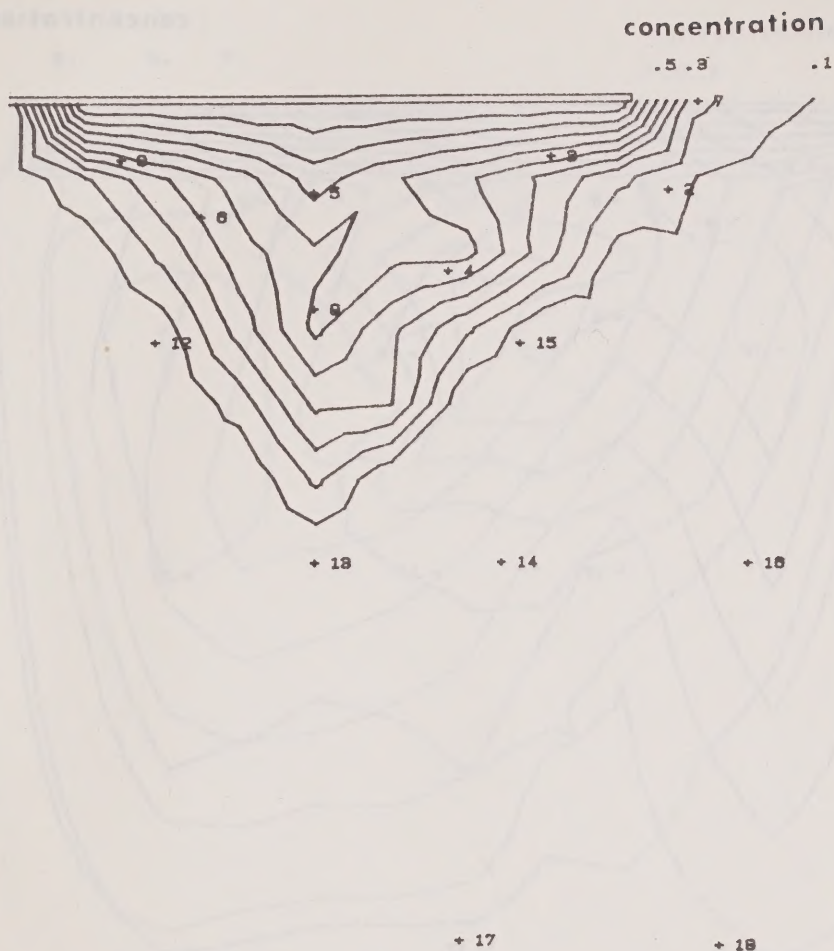


UNIONVILLE

BREAKTHROUGH CONTOURS
OF SODIUM WITH TIME
CONCENTRATION LEVEL

$$C/C_0 = 0.1$$

FIG 19 | 1: 188 | JULY 1980



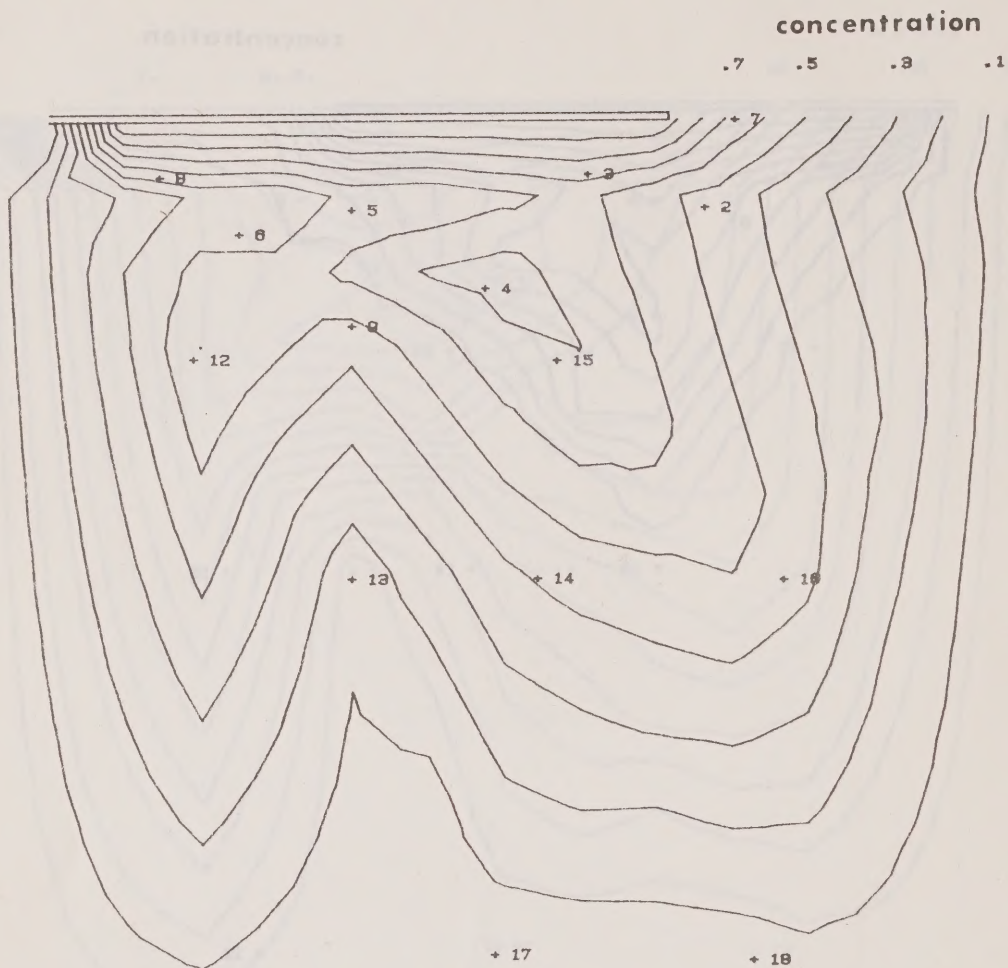
UNIONVILLE

WEEK 30
DISPERSION OF CHLORIDE
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG 20a

1:188

JULY 1980



DIRECTION OF GROUNDWATER FLOW

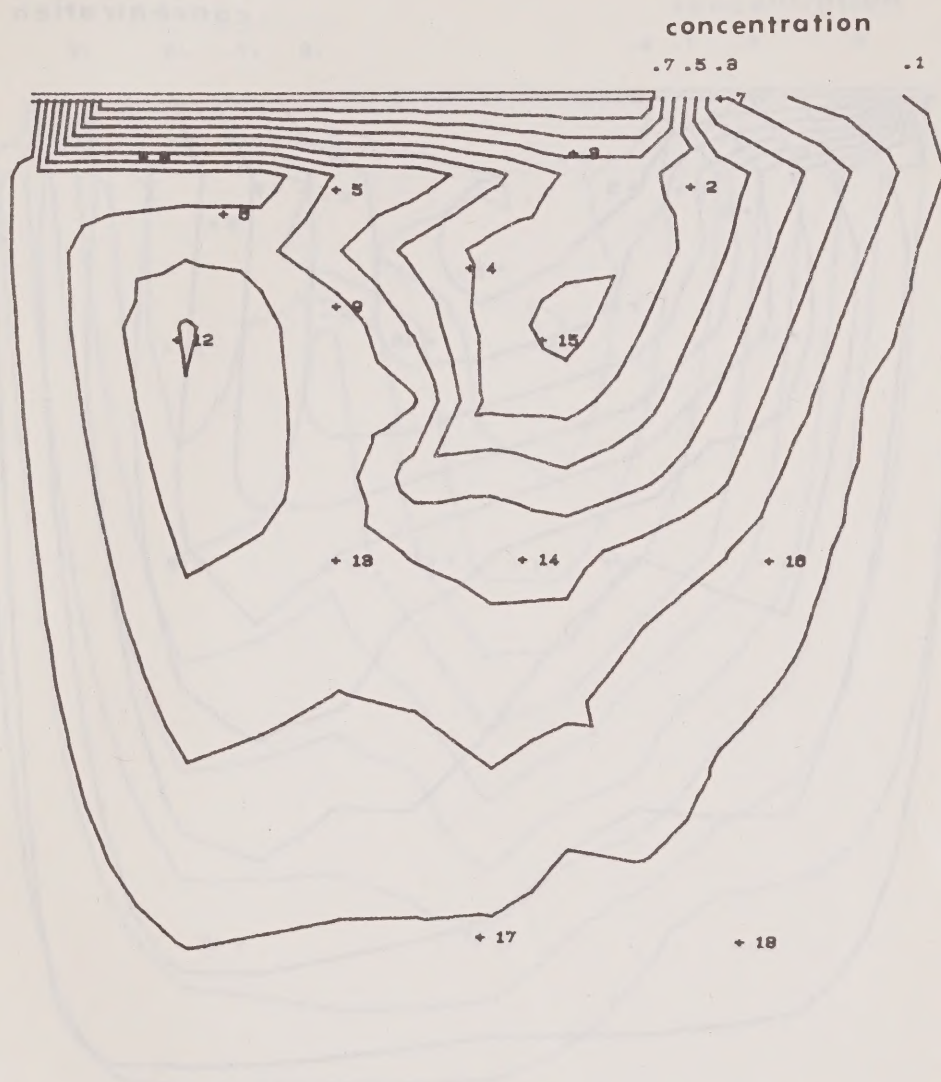
UNIONVILLE

WEEK 60
DISPERSION OF CHLORIDE
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG 20b

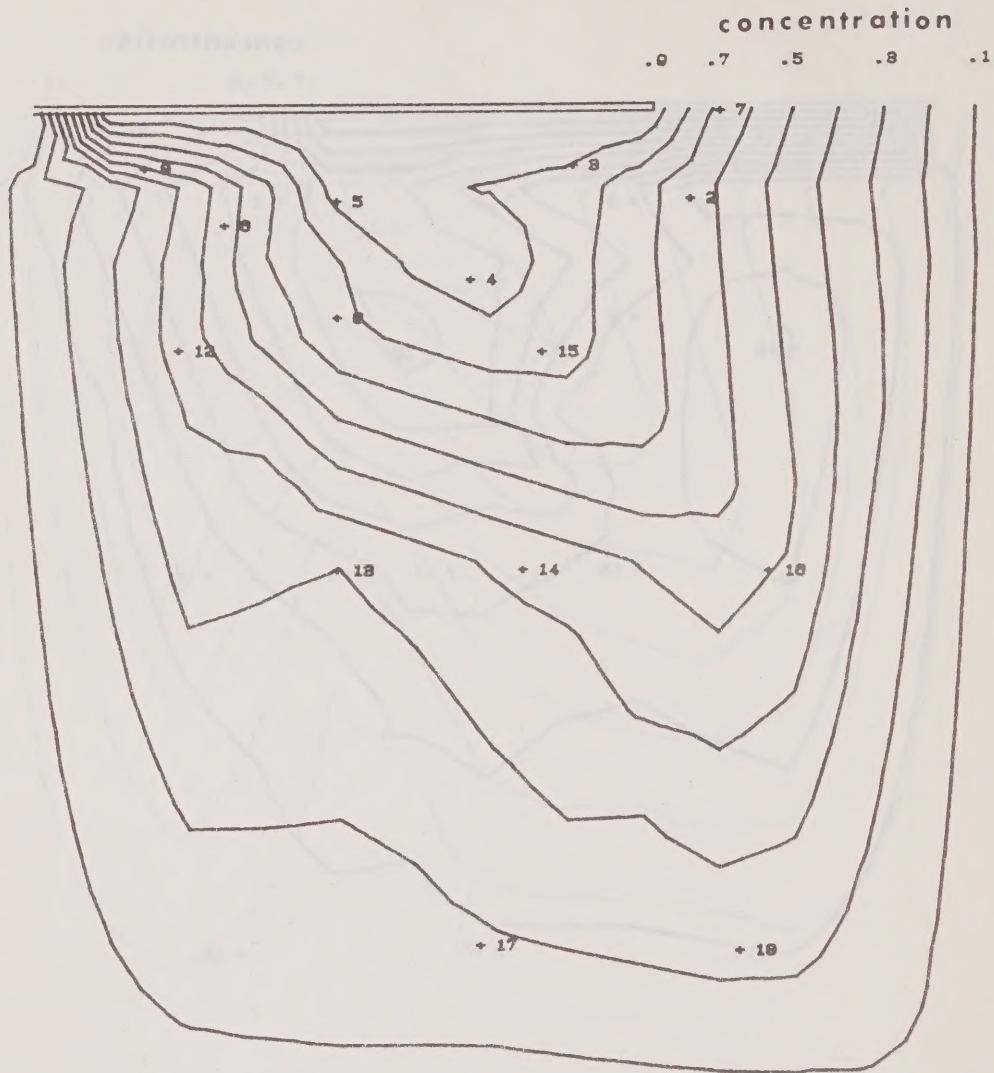
1:188

JULY 1980



DIRECTION OF GROUNDWATER FLOW

UNIONVILLE		
WEEK 90		
DISPERSION OF CHLORIDE AT THE SECONDARY EFFLUENT DISPOSAL SITE		
FIG 20c	1:188	JULY 1980



DIRECTION OF GROUNDWATER FLOW

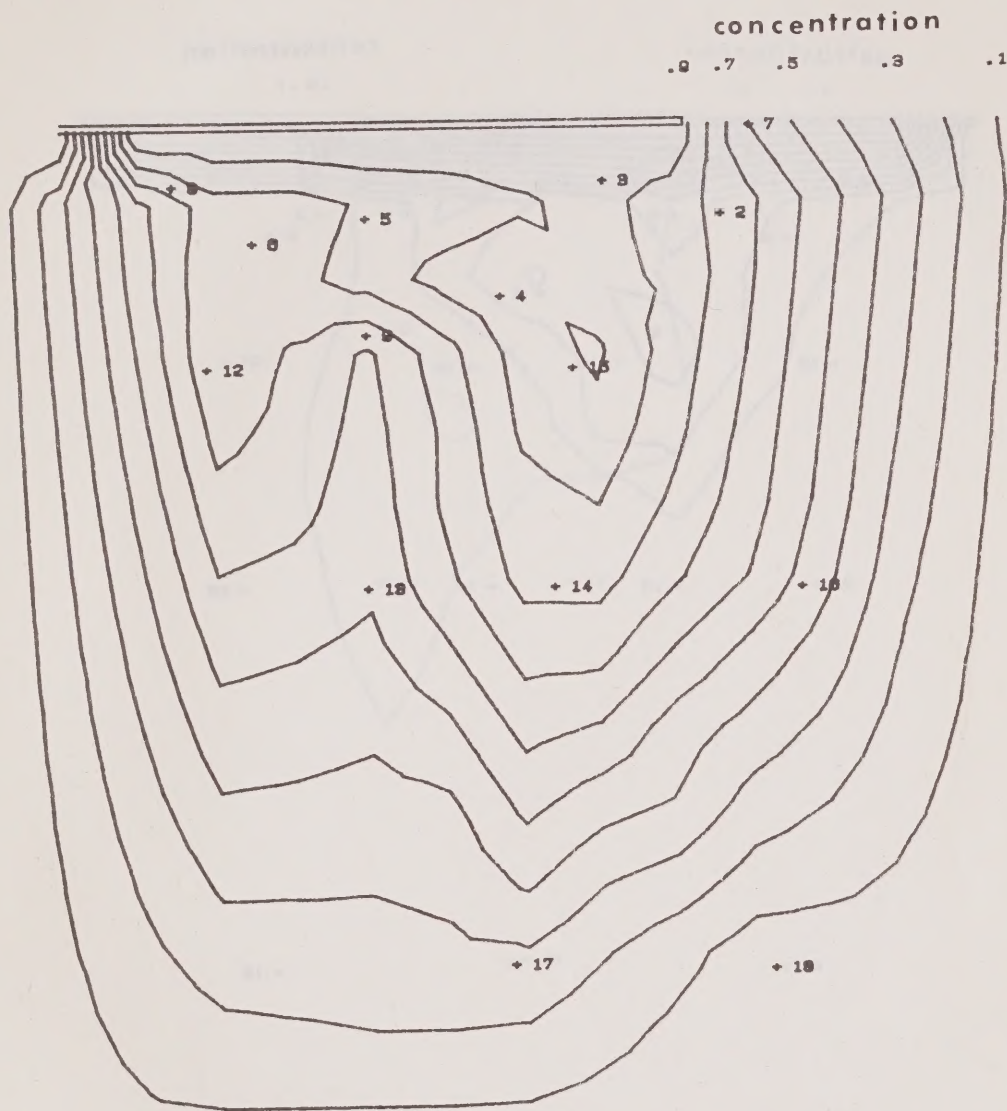
UNIONVILLE

WEEK 120
DISPERSION OF CHLORIDE
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG 20d

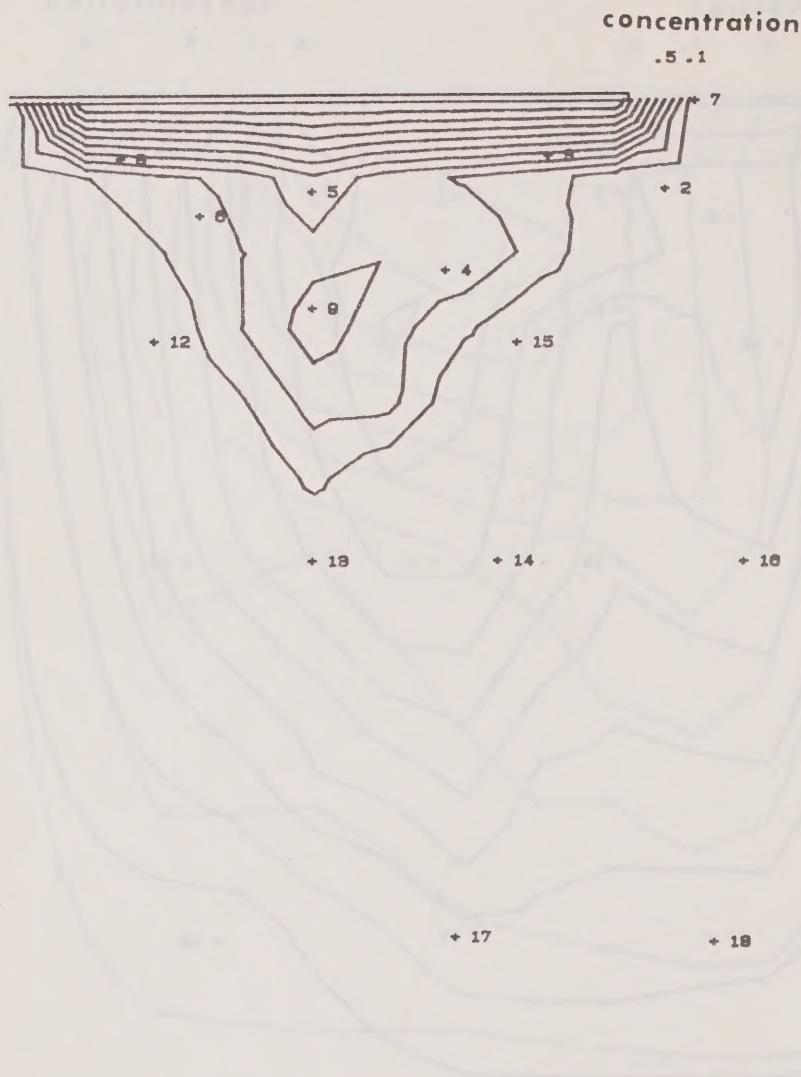
1:188

JULY 1980



DIRECTION OF GROUNDWATER FLOW

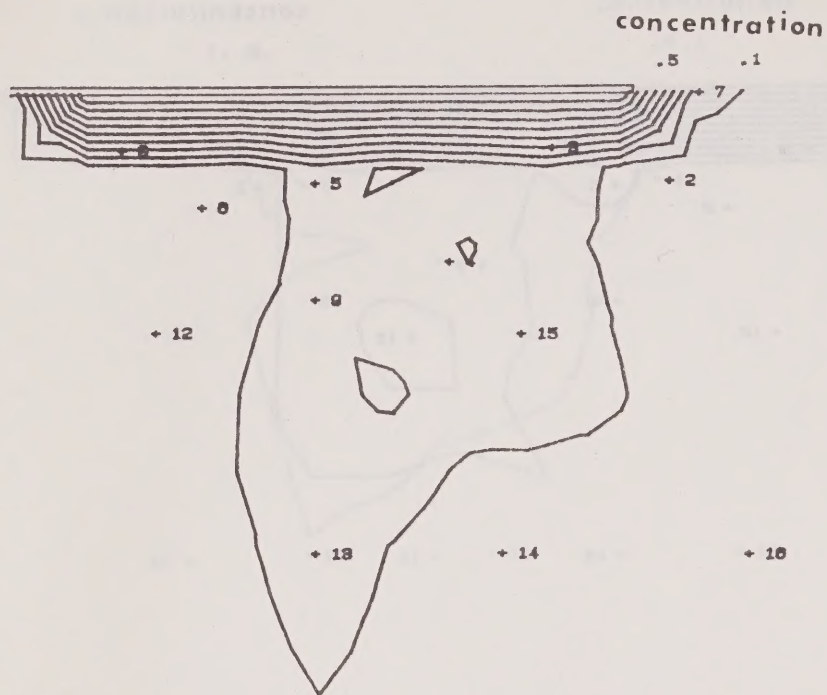
UNIONVILLE		
WEEK 143		
DISPERSION OF CHLORIDE AT THE SECONDARY EFFLUENT DISPOSAL SITE		
FIG 20e	1:188	JULY 1980



DIRECTION OF GROUNDWATER FLOW

UNIONVILLE

WEEK 30
DISPERSION OF NITRATE
AT THE SECONDARY
EFFLUENT DISPOSAL SITE



DIRECTION OF GROUNDWATER FLOW

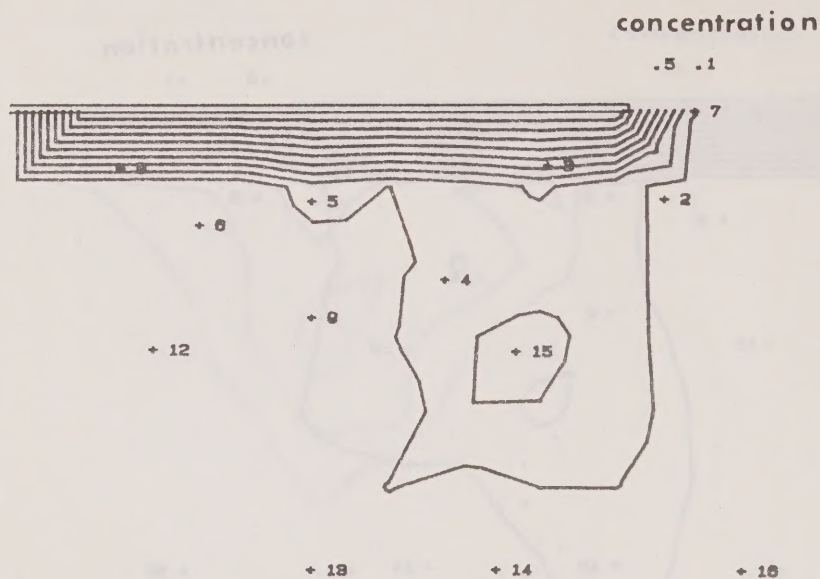
UNIONVILLE

WEEK 60
DISPERSION OF NITRATE
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG 21b

1:188

JULY 1980



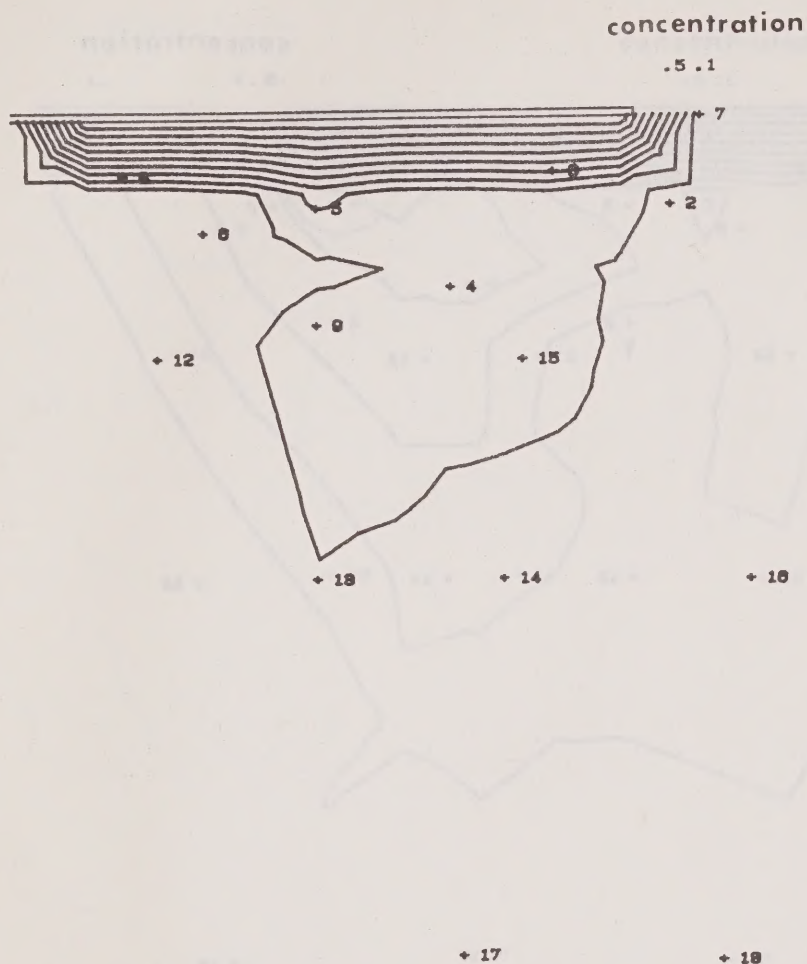
UNIONVILLE

WEEK 90
DISPERSION OF NITRATE
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG 21c

1:188

JULY 1980



DIRECTION OF GROUNDWATER FLOW

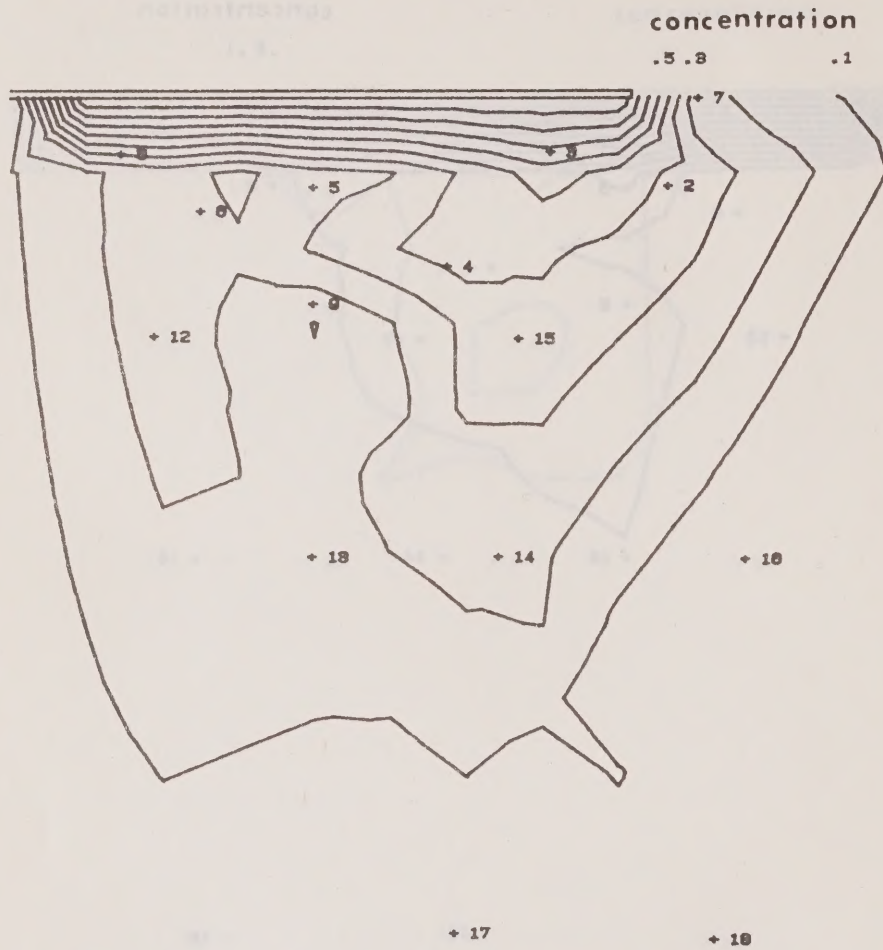
UNIONVILLE

WEEK 120
DISPERSION OF NITRATE
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG 21d

1:188

JULY 1980



UNIONVILLE

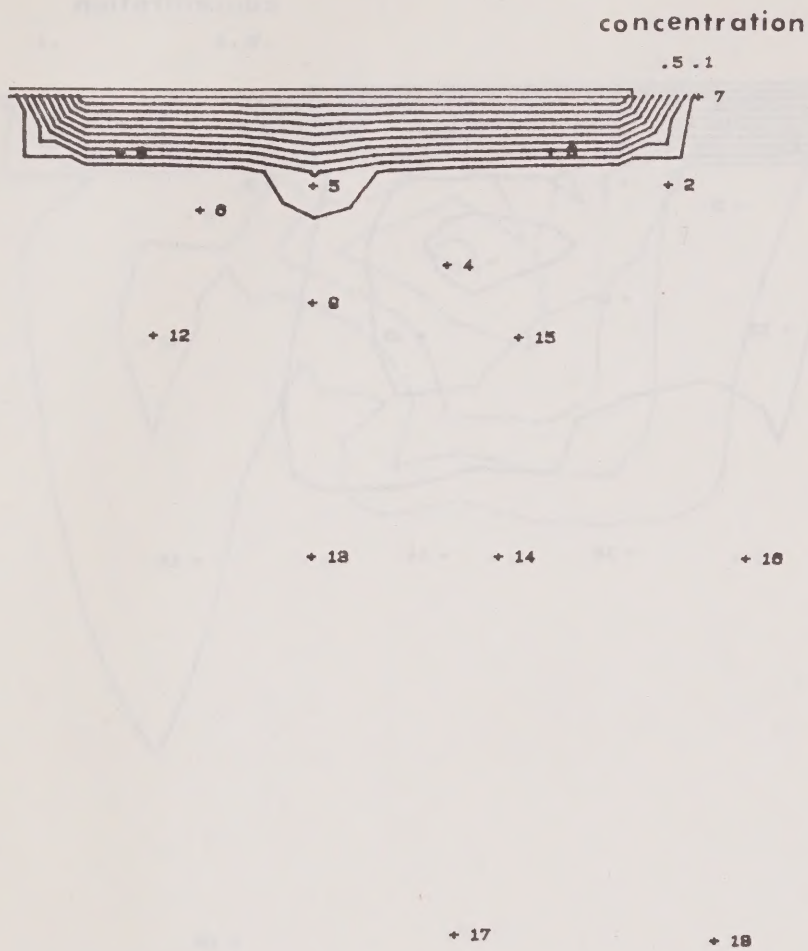
WEEK 143

DISPERSION OF NITRATE
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG21e

1:188

JULY 1980



DIRECTION OF GROUNDWATER FLOW

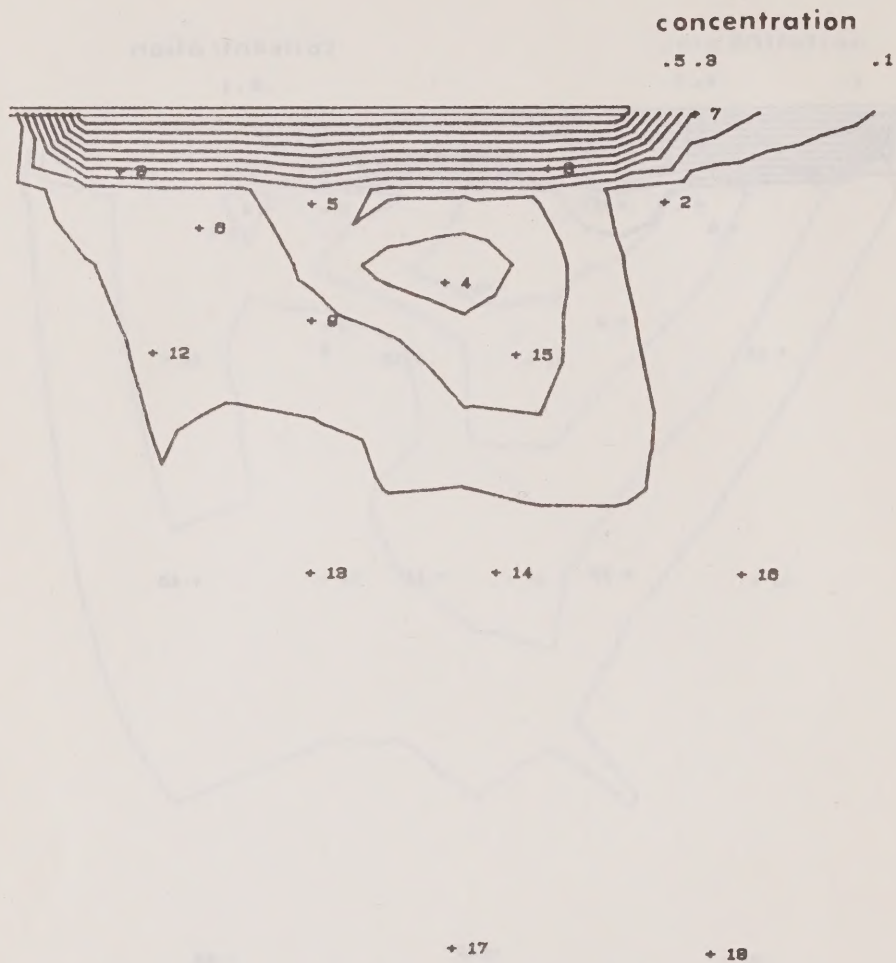
UNIONVILLE

WEEK 30
DISPERSION OF SODIUM
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG 22a

1:188

JULY 1980



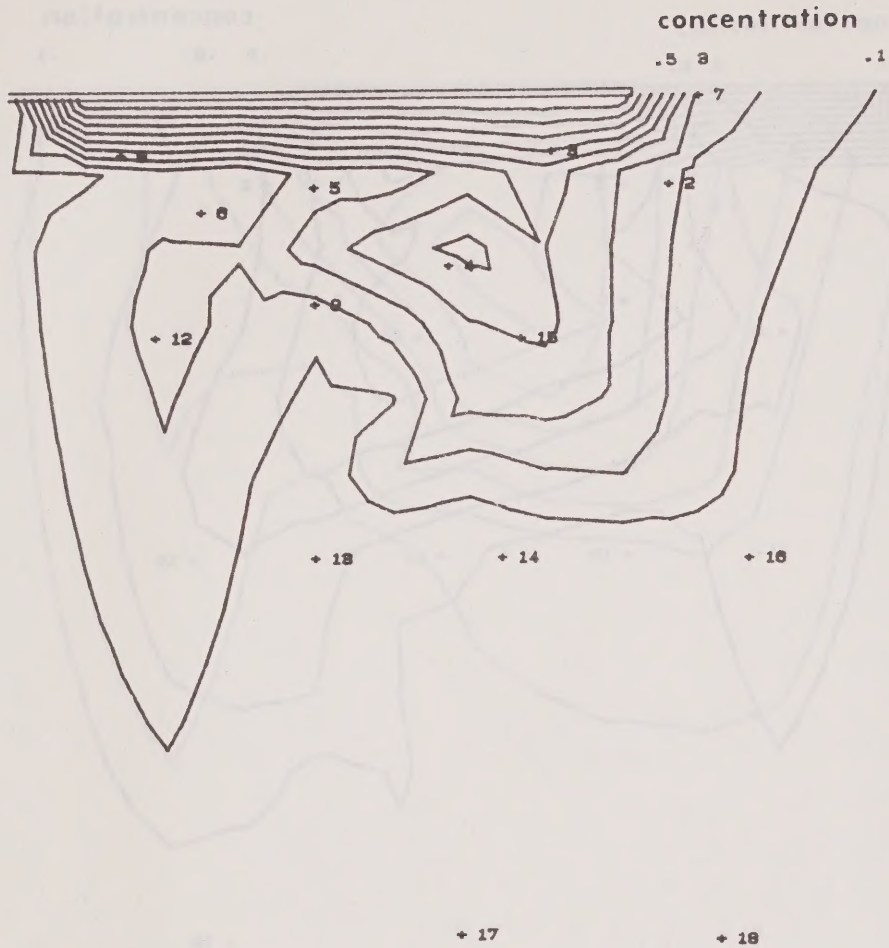
UNIONVILLE

WEEK 60
DISPERSION OF SODIUM
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG 22b

1:188

JULY 1980



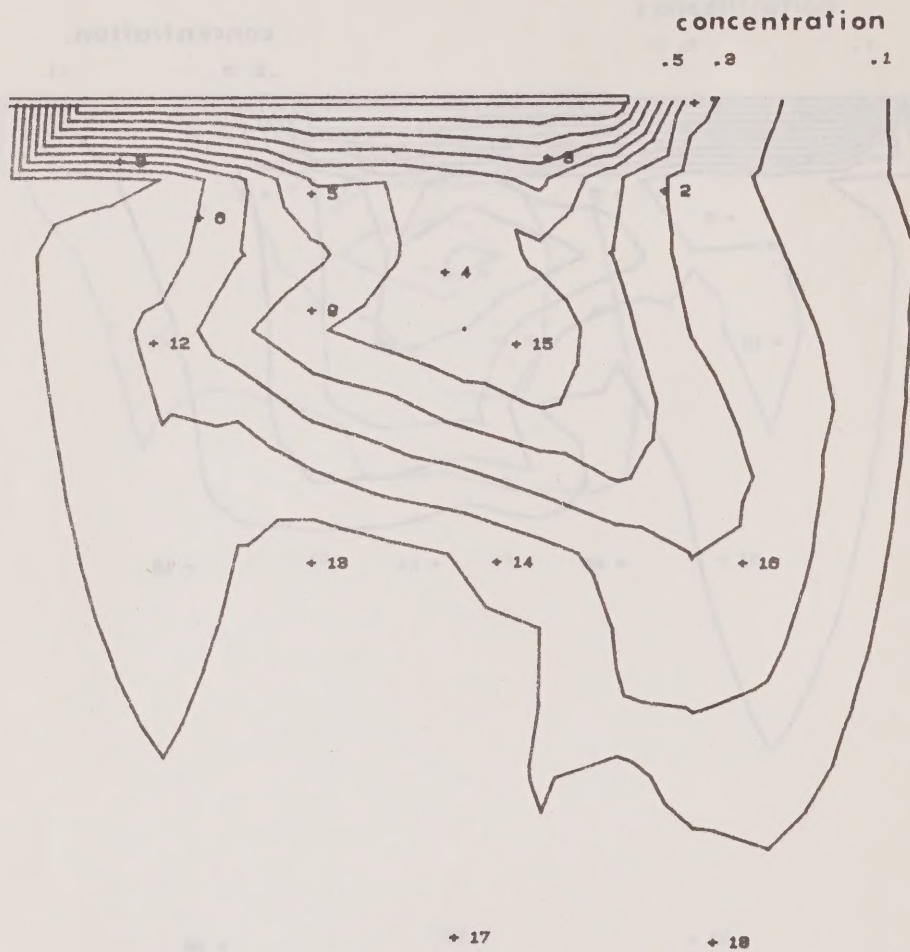
UNIONVILLE

WEEK 90
DISPERSION OF SODIUM
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG22c

1:188

JULY1980



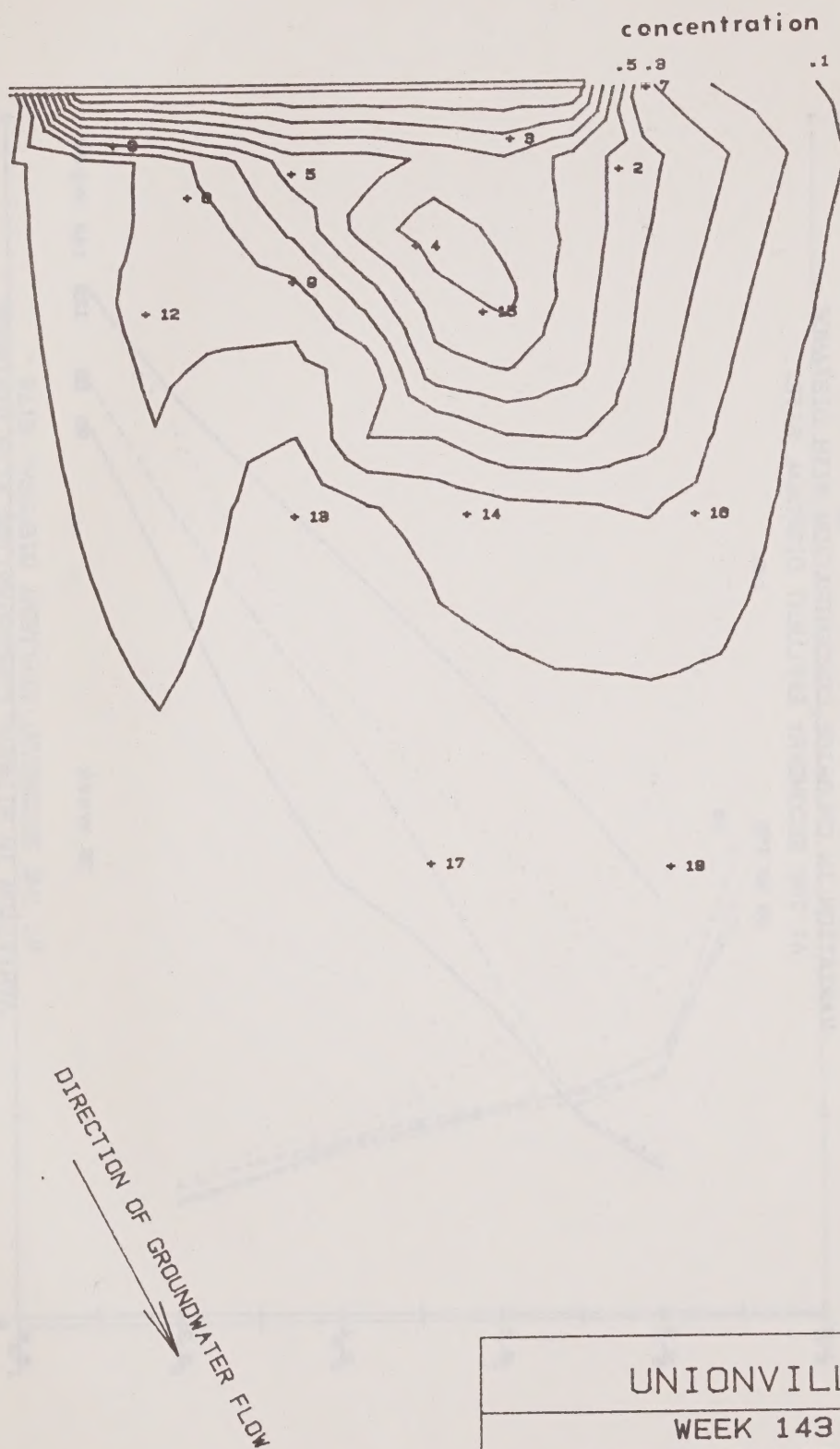
UNIONVILLE

WEEK 120
DISPERSION OF SODIUM
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG 22d

1:188

JULY 1980



UNIONVILLE

WEEK 143
DISPERSION OF SODIUM
AT THE SECONDARY
EFFLUENT DISPOSAL SITE

FIG 22e

1:188

JULY 1980

FIGURE 23

VARIATION IN CHLORIDE CONCENTRATION WITH DISTANCE
AT THE SECONDARY EFFLUENT DISPOSAL SITE.

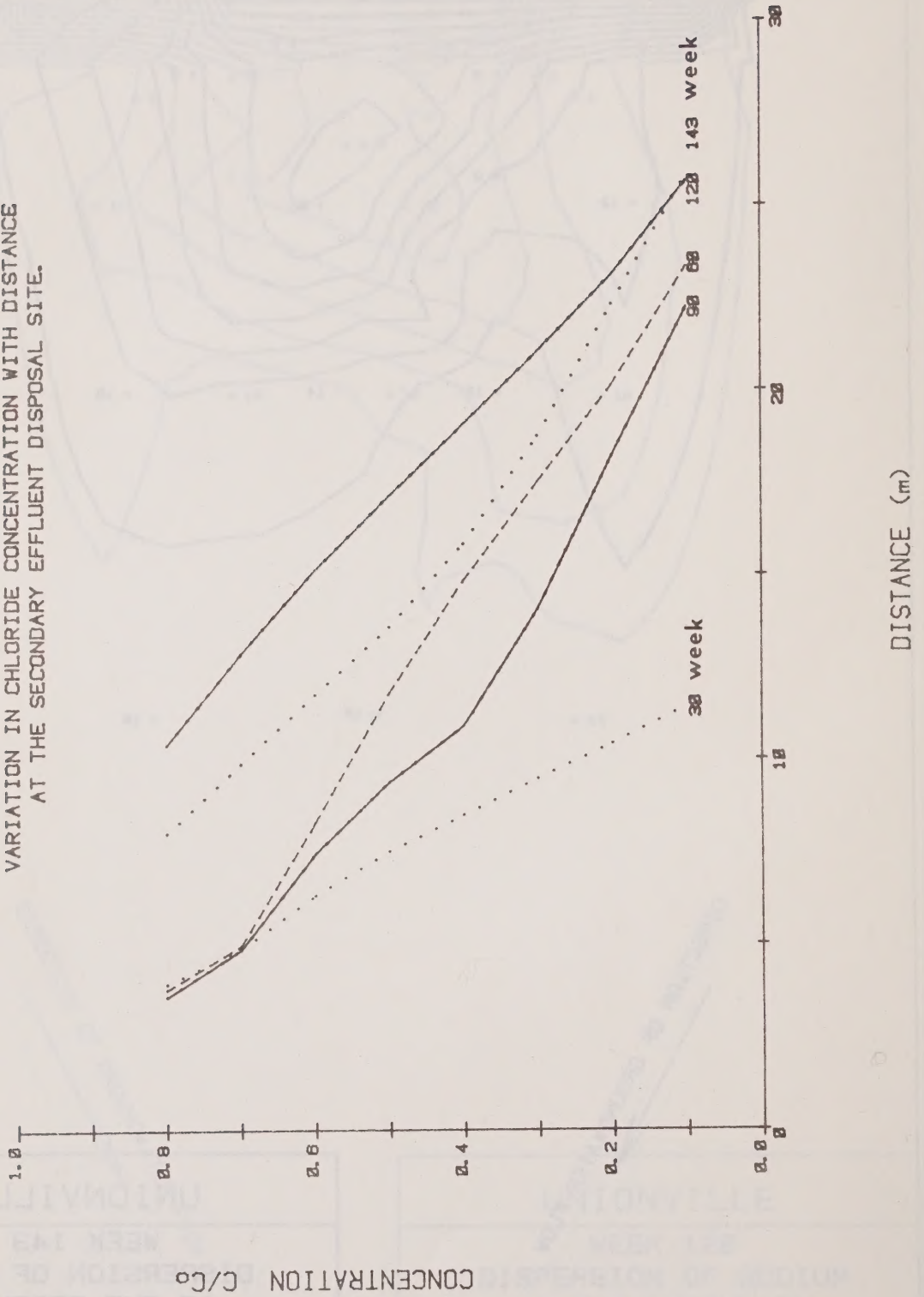


FIGURE 24

VARIATION IN NITRATE CONCENTRATION WITH DISTANCE
AT THE SECONDARY EFFLUENT DISPOSAL SITE .

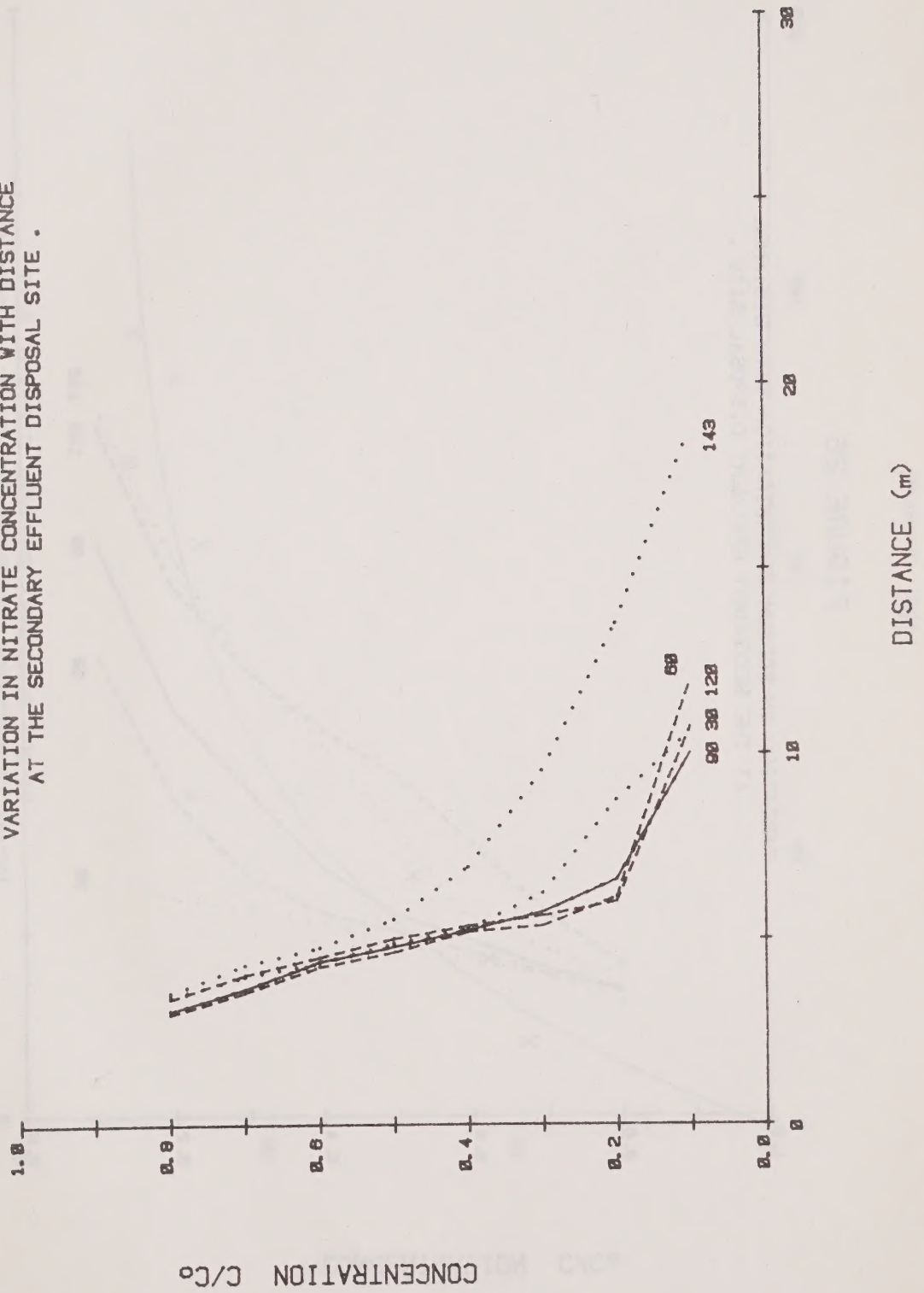


FIGURE 25

VARIATION IN SODIUM CONCENTRATION WITH DISTANCE
AT THE SECONDARY EFFLUENT DISPOSAL SITE .

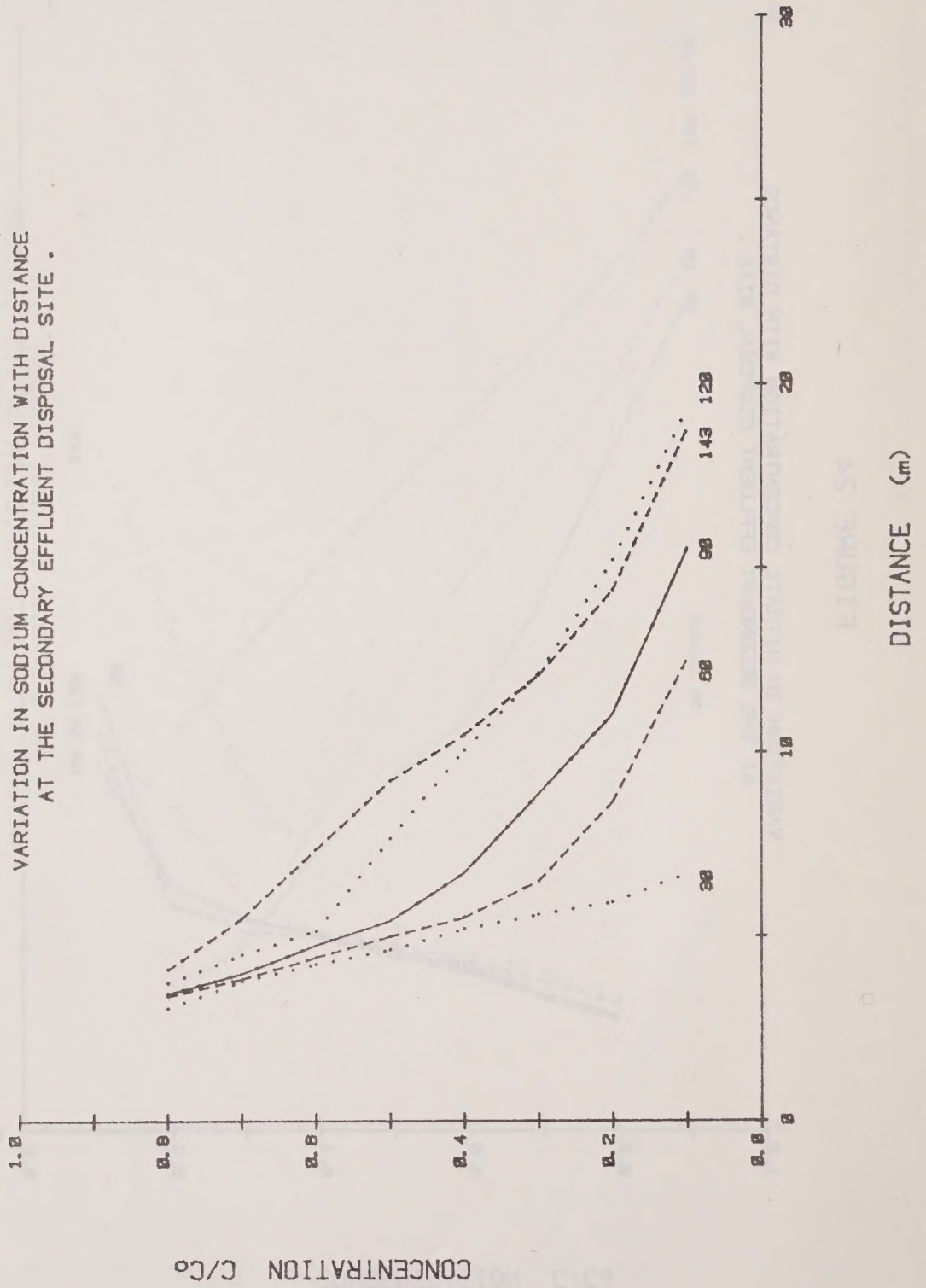


FIGURE 26

TRAVEL OF CHLORIDE CONCENTRATION LEVEL $C/C_0=0.1$
AT THE SECONDARY EFFLUENT DISPOSAL SITE.

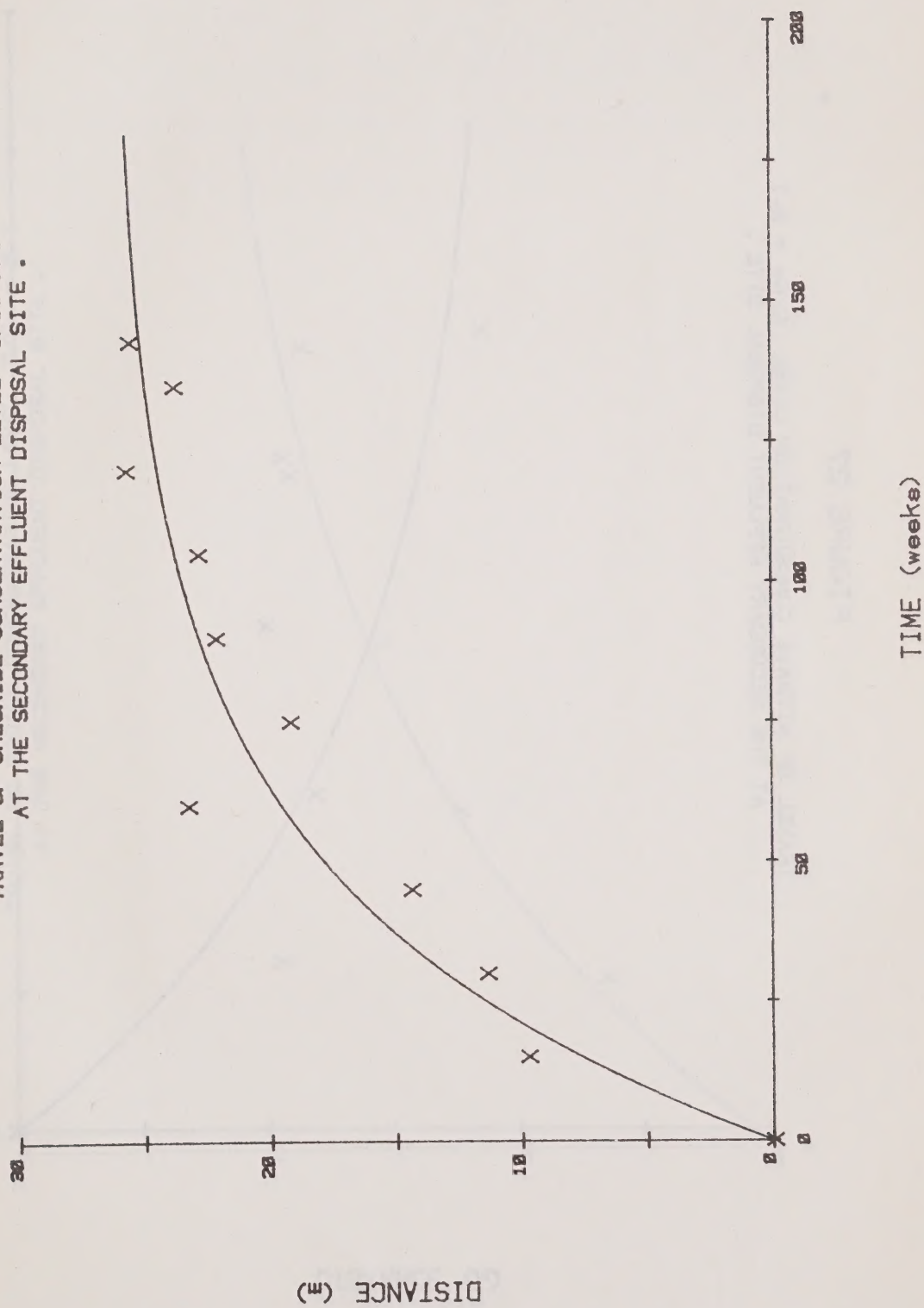


FIGURE 27

TRAVEL OF NITRATE CONCENTRATION LEVEL $C/C_0 = 0.1$
AT THE SECONDARY EFFLUENT DISPOSAL SITE.

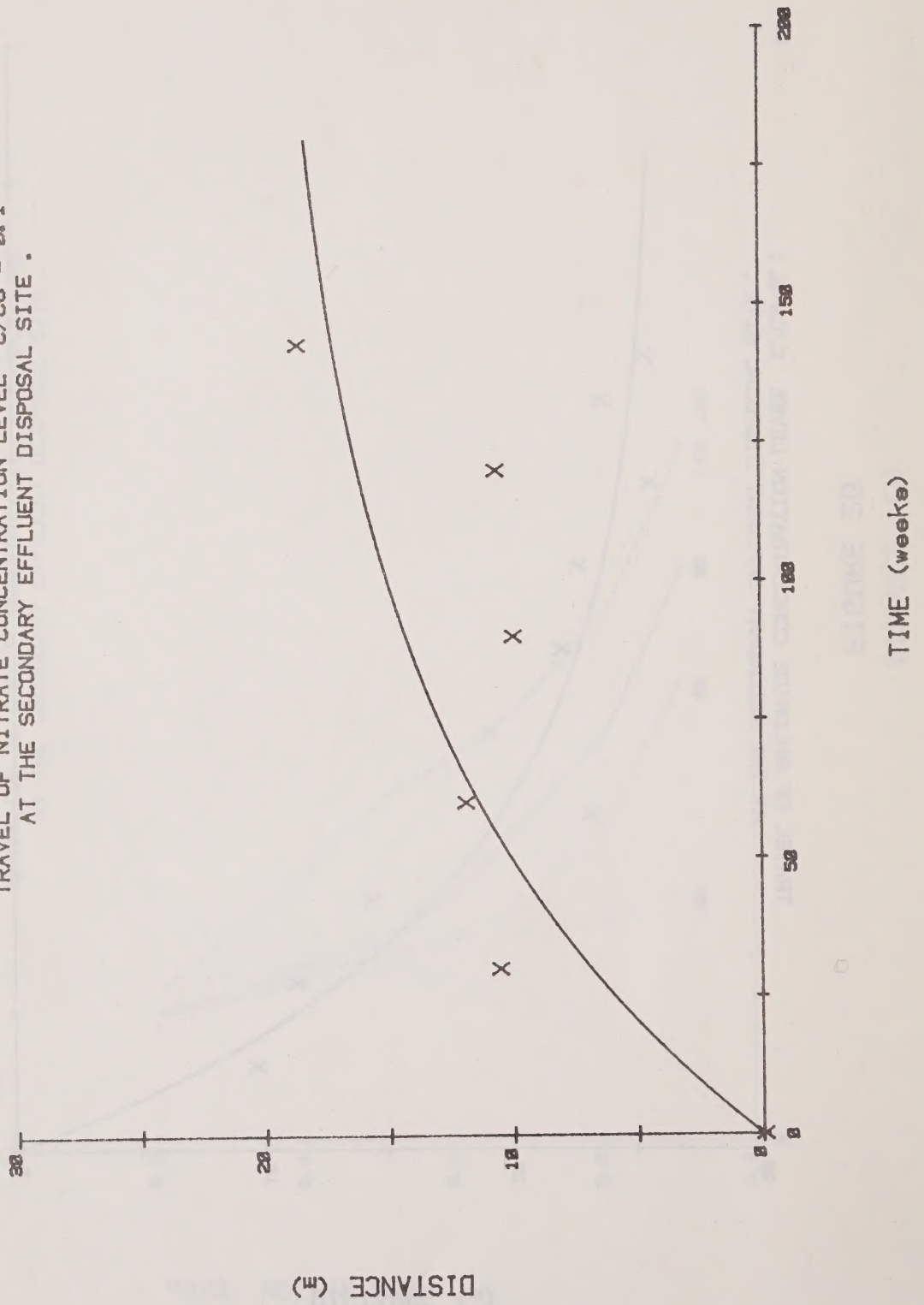


FIGURE 28

TRAVEL OF SODIUM CONCENTRATION LEVEL $C/C_0 = 0.1$
AT THE SECONDARY EFFLUENT DISPOSAL SITE .

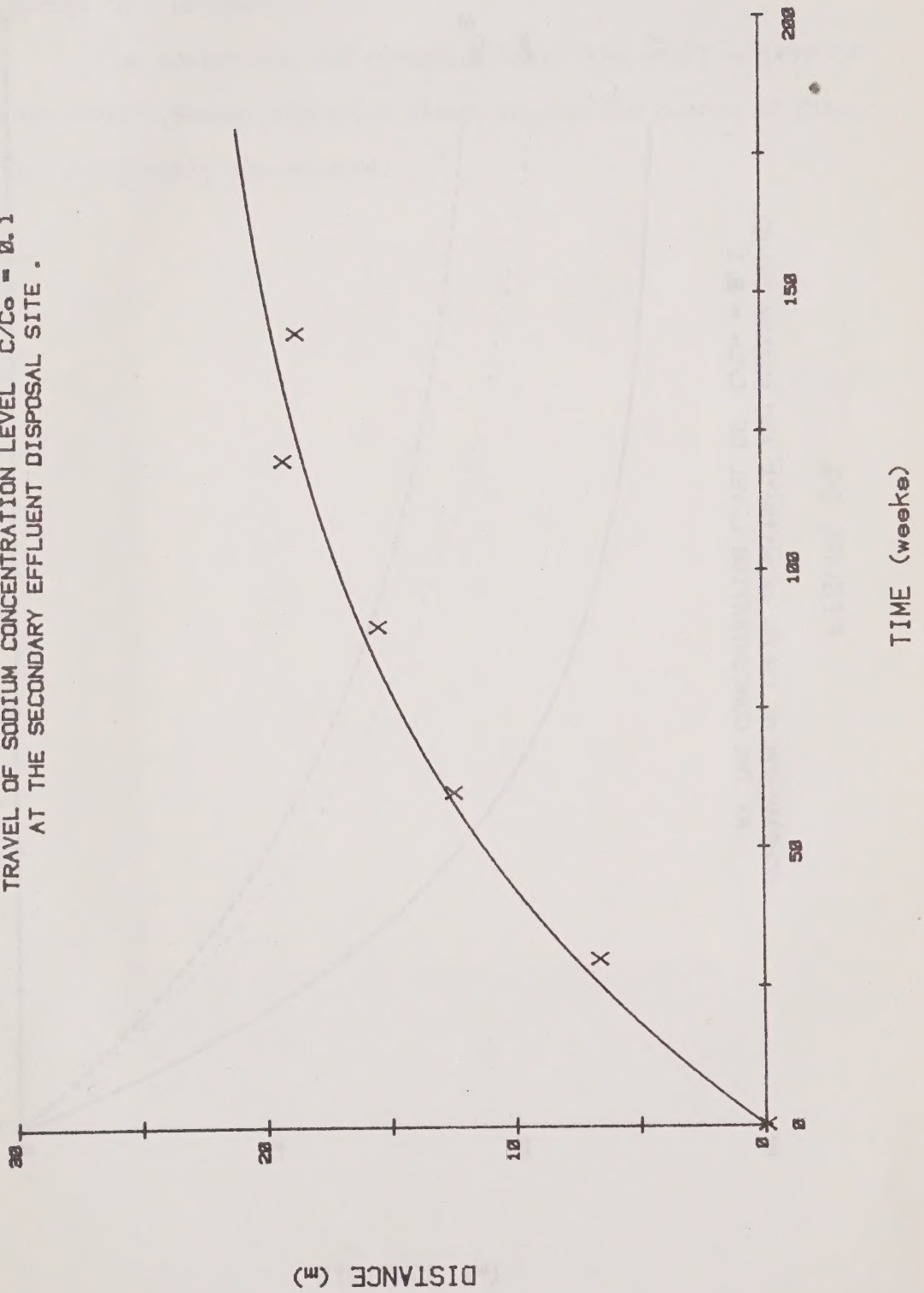
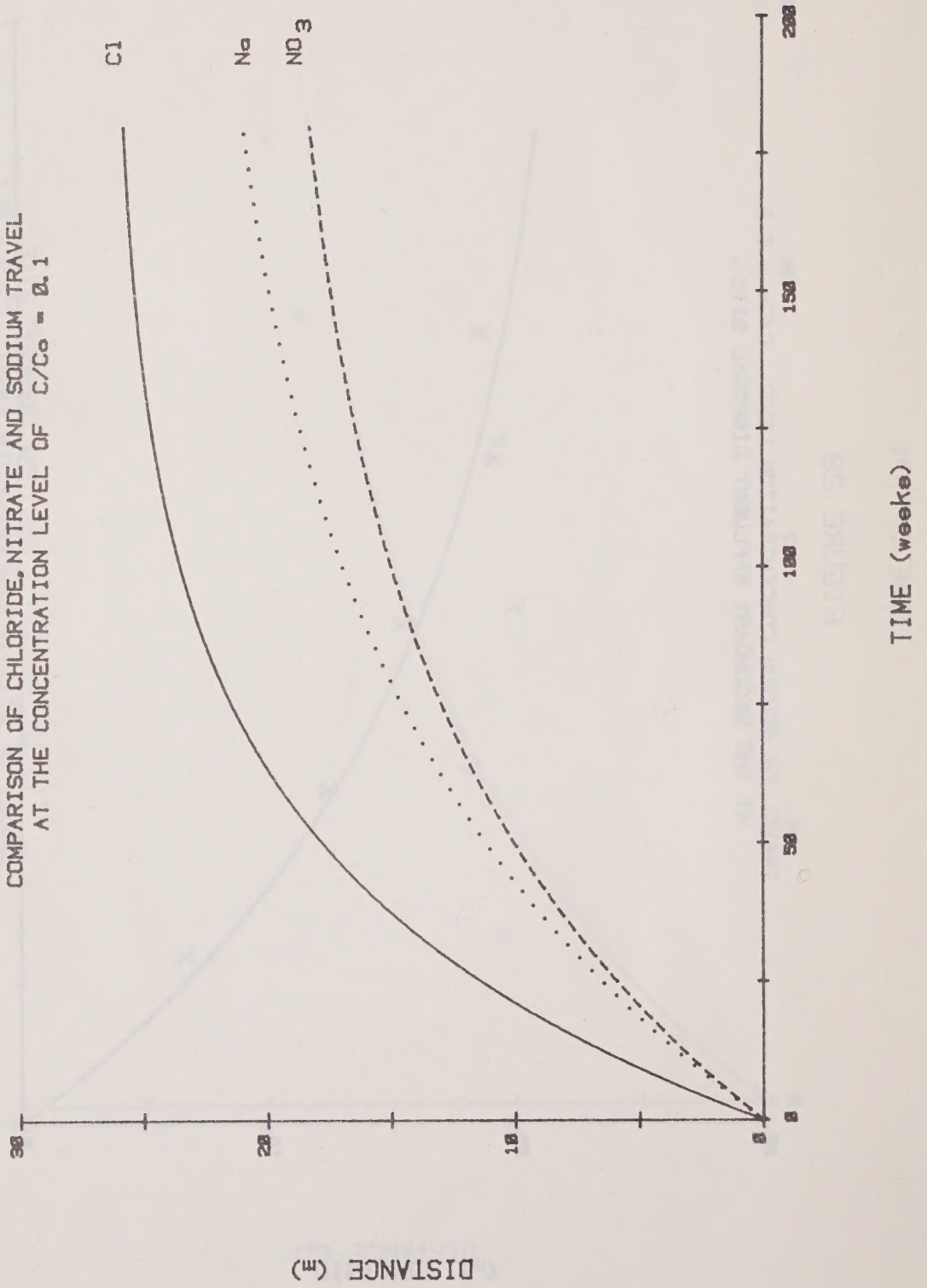


FIGURE 29

COMPARISON OF CHLORIDE, NITRATE AND SODIUM TRAVEL
AT THE CONCENTRATION LEVEL OF $C/C_0 = 0.1$



ACKNOWLEDGEMENT

Mr. A. V. Giffen and Mr. N. G. Ehlert, project engineers, left the services of the Pollution Control Branch before completion of the study. Mr. Giffen helped in the initiation and Mr. Ehlert conducted this project.

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Research Publication No.83

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LEACHING BEDS, 1980.

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